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Natural Resource Capital Formation in American Agriculture

Irrigation, Drainage, and Conservation, 1855-1980

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ABSTRACT

In 1980 irrigation, drainage, and conservation assets serving U.S. agriculture amounted to $44.3 billion (1977 dollars). These assets, called natural resource capital (NRC), represented about 25 percent of all depreciable nonland business capital in agriculture. Producers' durable equipment other than specialized irrigation equipment accounted for 43 percent of NRC. Nonresidential farm service structures made up the remaining 32 percent of all depreciable business capital. Farm homes, not an element of farm business capital, were worth $38.5 billion, or 13 percent less than the value of NRC on and off farms.

In 1980 the onfarm and off farm values of NRC facilities and associated equipment were almost equal, at $22.1 and $22.3 billion, respectively. The onfarm component represented about 14 percent of all depreciable (nonland) business capital on farms.

Keywords: Investment, capital growth, physical capital, natural resource development, irrigation growth, drainage development, soil and water conservation.

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Especially useful was Roy E. Huffman's Irrigation Development and Public Water Policy (Ronald Press, 1953). It uniquely blends the historical, political/institutional, and economic dimensions of irrigation, for both specialists and nonspecialists. There is also Alvin S. Tostlebe's pioneering work on The Growth of Physical Capital in Agriculture, 1870-1950 (Occasional Paper No. 44, National Bureau of Economic Research, 1954). While Tostlebe did not investigate natural resource capital formation, many valuable insights and procedural guidelines were obtained from his work.

An important basic document from USDA was Elco Greenshields' landmark report, Irrigation Agriculture in the West (Misc. Pub. No. 670, Office of the Secretary, 1948). It remains one of the few indepth accounts of how the western irrigation economy is organized and has evolved with reference to climatic and soils conditions.

Recent publications of C. Edwin Young, Arthur B. Daugherty, and Gordon Sloggett from the ERS Resource Economics Survey, 1975-1977, were also consulted. Numerous Federal research and policy documents, State Experiment Station research bulletins, and the various "Censuses of Agriculture, Drainage and Irrigation," taken since 1890 were also valuable sources. Vital periodicals were Agricultural Statistics (annual, USDA), the Survey of Current Business (monthly, Commerce Department), and the Irrigation Journal (bimonthly, Brantwood Publications, Inc.).

The assistance of all these people and offices in USDA and elsewhere is greatly appreciated, but none is responsible for any errors and omissions.

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SUMMARY

This report is concerned with historical investment rates and growth patterns for agricultural irrigation, drainage and conservation capital in the United States. Its theme is that these principal elements of natural resource capital (NRC) have the same conceptual standing in farm production as labor, land, machinery, and buildings. Complete time-series estimates ending with the year 1980 are developed for the real gross and net stocks of public and private fixed capital assets associated with irrigation, drainage and conservation activities in the United States. It was possible to estimate rates of investment and derive at least indicative estimates of gross and net capital stocks for drainage since 1855, irrigation since 1870, and conservation since 1935.

Gross capital stocks are accumulated gross annual investments less retirement or abandonments to date and represent the assets in service. Net capital stocks are the accumulated assets still in service reduced in value by the amount by which they have partly depreciated. The study uses a perpetual inventory method for deriving continuous capital stock estimates from annual investment rates and capital consumption (depreciation) allowances, beginning with the initial record years. All investment rates and capital-stock values given in this report, whether gross or net, are expressed in constant 1977 dollars. Here are some highlights:

o In 1980 the NRC facilities and equipment had a combined gross stock value of $63.9 billion and a net capital value of $44.4 billion, in 1977 dollars. They made up about 25 percent of the net value of all depreciable nonland business capital assets used for agriculture. Machinery and other producers' durable equipment accounted for 43 percent and farm service structures for the remaining 32 percent of depreciable business assets. The $44.4 billion real net value of NRC assets in 1980 was divided $23.7 billion (53 percent) for irrigation, $7.5 billion (17 percent) for drainage, and $13.2 billion (30 percent) for soil and water conservation.

o As of 1980 the Federal Government, either by direct construction or various cost-sharing programs, had contributed about 25 percent of all past investment funds for irrigation, about 5 percent of the funds for drainage, and 50 percent of the funds for conservation. Federal shares of net capital values in 1980 were 46 percent for irrigation, 4 percent for drainage, and 46 percent for conservation. The net capital percentage shares differ from source-of-fund shares because the capital shares must allow for the different rates at which various irrigation, drainage and conservation assets have depreciated over time.

o As of 1980, natural resource net capital in the aggregate was divided about equally between onfarm or individually owned measures, equipment and facilities versus those facilities of an infrastructural or group-owned and project character. Many of the latter, like large multipurpose irrigation reservoirs, canals and public drainage ditches, are built on or can cross fairly remote and nonagricultural lands. Net capital values for irrigation in 1980 were divided about 62 percent to 38 percent for project versus onfarm facilities. This compares to 74 and 88 percent back in 1940. These percentages confirm that irrigation in the United States has generally become much less dependent on governmental and other group projects.

o The same trend is evident but more gradual for drainage. Net capital values in 1980 for drainage were divided about 60 percent to 40 percent for project versus onfarm facilities. This compares with a 95:5 percent ratio back in 1940.

o The trend is opposite for conservation. Net capital values for conservation in 1980 were divided about 25 percent to 75 percent between project versus individual farm conservation measures and improvements. In 1970 the percentage ratio was 15 to 85 percent for project versus onfarm measures.

o The leading component of agricultural natural resource capital in the United States is presently irrigation capital. It will predominate in the foreseeable future. From 1976 to 1980 gross annual investments for all new irrigation facilities and equipment came to $1.4 billion per year. The Federal gross rate was $149 million per year. This was 11 percent of all new investment. The private or non-Federal rate was close to $1.3 billion per year, 89 percent of the total. The gross investment rates were divided $169 million (12 percent) for water storage and other project facilities and $1.25 billion (88 percent) for farmer purchases of systems and equipment.

o Concerning drainage, gross annual investments from 1976 to 1980 for all new drainage facilities and systems came to $175 million per year. Project drainage accounted for $30 million (17 percent) of this total, while independent farm systems accounted for $145 million (83 percent). Only about $10 million (7 percent) of the latter amount came from Federal cost-sharing under the Agricultural Conservation Program.

o Concerning conservation, gross investment from 1976 to 1980 for conservation purposes totaled $623 million annually. But depreciation allowances were $779 million. This gives a negative net investment rate and annual rate of decline in net capital of -$156 million (-1.15 percent). The 1976-80 average annual decline for onfarm conservation measures was actually -$230 million (-2.1 percent) per year. Conservation project facilities gained in net value, by about $74 million (2.5 percent) per year.

o Aside from significant declines in net capital values for conservation improvements, a noteworthy finding of this study is the sharp growth of onfarm relative to project irrigation capital. This rapid growth is directly associated with the widespread adoption of new sprinkler (pressure) irrigation technologies such as large center-pivot systems and other self-propelled and mobile irrigation systems, plus 'drip' irrigation.

o It further appears that pressure (sprinkler) irrigation capital grew at a much faster pace from 1976 to 1980 than did any other major component of farm business capital. Real land values declined by $380 million (0.1 percent) per year. Farm service structures increased in real value by $1.9 billion (3.6 percent) per year. Producers' durable equipment value rose by $2.1 billion (3 percent) per year, while sprinkler irrigation net assets grew by $633 million (12.3 percent) per year. These irrigation assets were divided about equally between water supply and water distribution systems.

o Between 1976 and 1980 center-pivot irrigation systems (CP) accounted for a good two thirds of all new net investment in sprinkler distribution systems

installed on farms. The CP net growth rate was 18.6 percent per year, starting from a 1975 base of 50 percent of all sprinkler distribution capital. For 'drip' irrigation, a recent technology, the 1976-80 net growth rate was 14.5 percent per year. New 'drip' installations accounted for 15 percent of the new net investment in pressure irrigation systems.

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INTRODUCTION

This report discusses and quantifies natural resource capital accumulation in U.S. agriculture. In addition to improving the structural basis of earlier time-series data, all basic information is updated to the year 1980. Equal attention is given to cumulative historical and real annual investments, and also to 'gross capital stocks' as approximating the original real cost of the improvements still in use. Further, real 'net capital values' are derived as measures of national wealth of farms and in agriculturally oriented natural resource development projects. Rational natural resource policies as well as intelligent farm production planning and general agricultural policies require such information. It is at least a qualitative indicator of the economic condition of the agricultural productive plant.

The information presented herein has a multi-user orientation. It should be helpful to legislators and other public officials as well as natural resource administrators and planners. Serious students of agriculture may also profit from it, especially those interested in agricultural history, economic structure, capital growth, public finance and productivity. While not addressed to individual farm and ranch operators, they will benefit by the information being made available to those who work directly with them, such as agricultural extension specialists and conservation planners.

CONCEPTS AND SCOPE

The American agricultural economy is often described as the most progressive and productive in the world because of the application of individual enterprise, science, and technology to virtually every phase of crop and livestock production. In short, agriculture in the United States in a capital-intensive industry. But what is the total size of this capital commitment? How has it changed, especially since the era of agricultural land expansion drew to a close (1)? 1/ What national assets, such as major irrigation and drainage projects works off farms, should be included in aggregate measures of agricultural capital? Which forms of irrigation, drainage, and conservation capital can be quantified, and what is their magnitude and direction compared with familiar capital items like buildings, machinery, and farm vehicles?

1/ Underscored numbers in parentheses refer to notes and references in Appendix A.

This report focuses on all of these questions, especially the last two. Productive capital accumulated in connection with irrigation, drainage, and soil and water conservation is more than an incidental part of the agricultural resource mix. It has the same conceptual standing as labor, land, and machinery inputs. It should be recorded in real terms, so that its practical importance on farms and ranches, as well as its contribution to national production, can be determined.

Natural resource investments and capital stocks represent some aspects of natural resource development and management which have a determinable or at least plausible relationship with agricultural production. Yet, the amount of capital invested in irrigation, drainage and conservation, and its changing net value, has not been systematically recorded and used for basic research, policy analysis, or situation and outlook analysis. This is rather surprising because in 1980, for example, irrigation, drainage, and conservation facilities and associated equipment had a combined net real value of about $44.3 billion, in constant 1977 dollars. They represented one-fourth of all fixed nonland capital investments in agriculture (2). In 1960 their combined net value was $37.6 billion, about one-third of all fixed capital in agriculture.

The study is concerned with regional and State irrigation, drainage, and conservation trends, but mainly from the standpoint of developing reliable aggregate acreages and capital values for the country as a whole. As records of natural resource investments for individual States and regions are spotty and of variable quality, only national totals are given in this report. Acknowledging that capital values bear only a rough relation to acreages improved or serviced, figures 1 to 3 show the States and regions where irrigation, drainage, and conservation activities are most concentrated. 2/

The spatial distribution of irrigation has changed the most in recent years. Census data for 1974, 1978 and 1982 indicate that irrigation has expanded most rapidly in Nebraska, southwestern Kansas, eastern Arkansas, Florida, southern Michigan, the lower Central Valley in California, southwestern Georgia, southeastern Alabama, Mississippi, North Carolina, and the Delmarva region (parts of Delaware, Virginia and Maryland). Bajwa has completed an original interdisciplinary analysis of the factors explaining irrigation expansion in Florida and the Middle Atlantic States (3). With Crosswhite and Gadsby he also investigated alternative methods for estimating irrigation water needs in humid regions (4).

Significant cutbacks in irrigation have occurred in recent years in southeastern Louisiana, southern Florida, New Jersey, southern California, Arizona and the western High Plains region, which reaches from the Texas Panhandle and adjacent New Mexico counties up to southeastern Colorado.

Background and Classification Process

The stimulus for this line of research was an exploratory study which indicated that public natural resource investments in agriculture had had a modest positive effect on real economic growth in agriculture from 1929 to 1972, accounting for perhaps up to 10 percent of the tendency for real gross farm

2/ All figures and tables are located in the appendices.

product (GFP) to increase over the period (5). While public resource investments had increased an average of 7.25 percent per year from 1929 to 1972, the resource-related partial rate of growth in real GFP was around 1.58 percent, giving a real elasticity of output of public resource investment of about 0.22. The main factors appearing to be positively related to agricultural growth during 1929-72 were research and extension activities, business inventory accumulations, and investment in producers' durable farm equipment.

In a later study of income and product accounting in natural resource development, a more complete and detailed set of capital-stock data covered specific natural-resource-related investment activities in agriculture. The chief limitations of the initial information covering 1929-72 were the omission of the important drainage and irrigation developmental period before 1929, the highly aggregated nature of the data set, and its restriction to public expenditures, not all of which could correctly be regarded as capital outlays.

In this report separate investment and capital stock series extending from 1900 to 1980 are defined for irrigation, drainage, and conservation. They are also subdivided up to five principal ways: (1) Whether Federal, non-Federal, public, or private financing was involved; (2) whether the facilities were farmer-owned and located on farms, or of a group-owned project nature; (3) whether gravity versus sprinkler irrigation methods were used; (4) whether farm drainage was with ditch systems versus buried tile or other subsurface systems; and (5) according to the specific legislation which authorized or encouraged private investment or Federal participation. The fifth category tends to automatically identify the respective program interests of administering Federal agencies and Departments. Together with the 11-item accounting system used, this classification scheme gave about 365 data time series to reconstruct or calculate.

Federal Statutory Authorities

Historical analyses of capital growth, where public and private investment are both involved, must recognize the basic authorizations that permit and, in many cases require, public expenditures. These analyses not only point out the different development purposes and data sources requiring study but can reveal why public inputs were considered necessary to promote particular public interests.

Some important State programs have permitted capital contributions for irrigation purposes, most notably in California, Montana, and Utah. However, the Federal Government has been far more active in this respect.

Many national laws authorize Federal creation of NRC either through direct construction, design help, or cost-sharing. Those most relevant to this work are the Reclamation Act of 1902 (for irrigation, irrigation-associated drainage, and other multiple purposes for water development); the Agricultural Adjustment Act of 1933 (soil conservation, water pollution control, and some elements of farm irrigation and drainage); the Flood Control Act of 1944 (conservation and watershed land protection); the Watershed Protection and Flood Prevention Act of 1954 (conservation, watershed land protection, and water management); the Agricultural or Soil Bank Act of 1956 (conservation); and the Great Plains Conservation Program (soil conservation and irrigation).

Under the Reclamation Act and subsequent related laws and amendments, the Department of the Interior administers nearly all Federal irrigation construction activity, mostly through its Bureau of Reclamation (USBR). Some irrigation installations have also been built by the Bureau of Indian Affairs and Corps of Engineers. Other Federal programs involving cost-sharing, technical assistance, and loan programs are funded and supervised in the U.S. Department of Agriculture (USDA), principally by the Agricultural Stabilization and Conservation Service (ASCS), the Soil Conservation Service (SCS, and the Farmers Home Administration (FmHA).

Plan of Report

Real form and visibility distinguish physical capital from such other assets as stocks, bonds and bank accounts. But what significance does physical capital have beyond the fact that it can be seen and classified? How can an economic value be placed on a stock of capital consisting of many different things purchased and/or built at different times? Such questions point to a need for consistent and workable definitions.

In this study, the same 'stock' of capital assets is defined at two economic levels: the 'gross capital stock' represents all assets still in service, valued at their original real cost; the 'net capital stock' is the gross stock reduced in value by the amount by which it has declined in value so far.

The gross-net distinction for capital stocks requires that the terms 'capital' and 'investment' be defined, measured, and properly related to each other. The three sections on theory, composition, and assumptions constitute the methodological core of this report. The theoretical framework first reviews the technical economic meaning of capital and investment. Translating these definitions into empirical estimates requires a formal method of measurement and accounting. The perpetual inventory method is used for this purpose.

The next step specifies the tangible components of irrigation, drainage, and conservation capital. The third basic section details procedural assumptions, general problems of estimation, and problems of estimation peculiar to irrigation, drainage, and conservation activities.

Results of the work are then discussed for all natural resource capital (NRC) in the aggregate compared with land and other major classes of fixed business capital in agriculture. Findings for specific NRC components--irrigation, drainage and conservation are discussed in more detail. The report ends with a few recommendations and observations concerning additional uses of the study.

For easy reference and comparison all statistical tables and charts are listed and consolidated in appendices B and C, with appropriate explanations. Not all of these are mentioned in the main text, because the tables and illustrations are arranged to stand alone in summarizing the work for readers with special interests.

THEORETICAL FRAMEWORK

This section focuses on the concepts and definitions behind the statistical data and conclusions involving irrigation, drainage and conservation assets as natural resource capital (NRC) and as capital in general.

The Meaning of Capital Value

Economists attach great significance to 'capital', ranking it with land, labor, and management as one of the four primary factors of production. But what really constitutes capital is often very unclear. This is most evident in discussions of economic philosophies, especially those of a controversial nature. The difficulty is also encountered in everyday business and finance, in economic planning, data gathering, and even in research studies on growth and wealth. An unsettled terminology has produced fuzzy ideas about capital and its corollary 'investment'. Fuzzy ideas impede communication and thus lead to ambiguous real-world information.

In this work capital is examined and evaluated as having one primary origin, regardless of its physical form. It comes from past production and was a part of income, more definitely, that share of prior income that was earned in producing investment goods as opposed to consumption goods and services. This concept, basically the notion that capital, potential production, and consumption can be linked systematically to past sources of income, is borrowed from Irving Fisher (6). Fisher is famous mostly for his innovative and somewhat controversial monetary theories, especially his rather novel equation of exchange, but his contributions to the appraisal of investment, risk, capital formation and efficiency were very substantial too. He calls income the "alpha and omega of economics", and then explains how future incomes are embodied in the term 'capital value' and how material wealth is fundamentally the means to income.

Fisher's work also includes an early exposition of the internal rate of return and other criteria for evaluating the profitability of investment alternatives. Such principles are subsumed in 'benefit-cost analysis' which, beginning in the 1950's, has been widely used in evaluating the economic feasibility of natural resource development (7).

A second view of capital is that it can originate also as gifts in nature that, through human intervention, if only by discovery, acquire an economic value. They may or may not be consumable in their natural state. But if they can be processed and/or traded in some fashion, they acquire value and can be used to generate new production and income. Land, air, water, minerals, petroleum, fish, wildlife and even scenery are in this sense 'capital'. They differ only in appearance from factories, equipment, and other manufactured or constructed capital assets.

The climatic, geologic and other natural evolutionary phenomena explaining the planet Earth as we live on it today could be claimed on a sort of philosophical level to be a type of accretionary production without prior human consumption. In such a setting reinvestment and possibly 'disinvestment' are rolling processes. Capital builds on capital according to natural forces. In this

event the primary origin of capital specified earlier--unexpended prior production--is not weakened but actually becomes more sufficient and complete.

Even so, it is easy to become enamored with the idea that capital arises spontaneously, at least in nature, and to commingle man-made assets with land, other natural resources and indeed, any pleasant aspect of the environment. Land itself has been defined in many ways, few of which are brief and to the point. Fewer still are restricted to its original connotations of territory, area, space and fertility.

Chryst and Back perhaps give land its briefest and most workable economic definition when they merely call it "the natural environment--those forces or opportunities existing independently of man's activities and which contribute to the state of his well-being." Their proposed criterion is that to be land, a resource must be beneficial to man <u>in a natural state</u>. On their reasoning that part of property value attributed to inherent productivity or location would be called a land resource. That part due to any improvements, including additions to soil fertility, would not be considered 'land' (<u>8</u>).

Installing grassed waterways in a cornfield, terraces for a mountain vineyard, or concrete drops to block the upslope encroachment of gullies are all fairly durable improvements if properly maintained. They call for substantial immediate outlays of money to pay for necessary machine work, materials and labor. These expenditures are clearly of an investment nature. They are drawn from someone's past income with benefits expected to accrue in the future, so the created improvements become fixed capital assets.

Conversely, other human actions, and some inactions as well, may result in declines (disinvestment) in the value of land improvements, and sometimes in the outright creation of social liabilities. Careless farming practices, poorly located feed lots and industrial plants, and a lackadaisical attitude about maintaining improvements are prime examples. Recalling our second view of capital, degradation of the natural as well as the improved environment amounts to a very real form of disinvestment in a society's stock of resources (<u>9</u>).

Let us return briefly to the problem of distinguishing between the value of land compared to improvements. For some situations, evolving agricultural economies for example, it is sensible to set up an a:b question. In (a) we visualize pure land as Chryst and Back see it. In (b) we include those improvements to land that will become part of a country's capital asset structure and thus may compete with farm mechanization opportunities and even with industrialization and other investment options that exist outside of agriculture. Determining the marginal efficiency of capital tied up in the improvements requires information on the stock of capital represented in (b) as well as the added production that can be attributed to this capital stock. It would then seem that total land or real estate value is the sum of the pure component (a) and the created component (b).

There are, however, at least three difficulties in applying this kind of analysis. One is that an interaction of capital and necessary labor inputs with pure land can affect production in a manner such that the marginal contribution of each input, and thus its economic value, cannot be isolated very well. This

is particularly true when resources are combined in fixed proportions, like budgeting so many dollars per acre for a recommended 'package' of improvements.

A second problem is that land generally does not exist very abundantly or at least for very long in its so-called pure state. Its pure values quickly fade into a composite value also encompassing improvements, even though the latter may be confined to minimal clearing and fencing (10).

A third difficulty is that for all but subsistence economies nonagricultural demands will tend to develop for agricultural lands. In transitional periods agricultural and nonagricultural uses and values may be combined. This makes it more difficult to impute market values to pure land versus the differently oriented capital improvements. For land gone over completely to urban or other nonagricultural purposes we still have an a:b question. This time it involves (a) pure site value, distinguished from (b) the value of appurtenant nonagricultural structures and other fixed capital improvements.

Despite their importance we cannot cover herein many such land use transition topics. Many of them simultaneously interface with open space, agricultural land and urban land. Most relevant to this report are some studies of Gibson and Timmons in Iowa, especially their concern with how land use shifts are influenced by public investments, presumably for any purpose, including the enhancement of land for agriculture itself through public conservation programs and resource development projects (11).

Before leaving the subject of land versus capital, the term 'fixed capital' should itself be explained as it will be encountered again. Fixed capital encompasses assets that retain their physical form and do not need further processing in yielding their design level of services. Farm machinery, vehicles, highways, houses, service buildings and airports are some everyday examples (12).

There is a logical but deceptive connection between fixed capital viewed in this manner and the idea of fixed costs--costs that do not vary with production, such as depreciation, interest charges, property taxes, and insurance. Of these items depreciation is most definitely related to fixed assets, so the labels fixed and depreciable capital are sometimes used interchangeably. A possible third synonym is the term instruments of production.

The label circulating capital as the opposite of fixed capital is encountered less frequently, perhaps because it is easily confused with money circulation as such and depends on one's point of view. Its originators had in mind assets that must undergo changes in form in yielding useful services, like raw materials and various fuels. Seed wheat on farms, wheat awaiting processing in flour mills and the flour on hand in bakeries are all legitimate examples of circulating capital, thus the point-of-view problem.

To summarize the discussion of capital and its meaning for this work, the emphasis is on fixed capital and created physical assets, but land is also regarded as an extremely important and distinct class of agricultural capital. A rigorous analysis of the pure value of land as Chryst and Back define it was not practicable, however, nor was it really essential for estimating stocks of natural resource capital. Nevertheless, some estimates of agricultural

land values residualized from general farm real estate values and natural resource capital are given later (table 1).

Nonland forms of physical agricultural capital include inventory-type holdings of standing or stored crops, inventories of livestock and poultry, and then all types of fixed agricultural assets. Fixed assets in turn include all farm buildings, vehicles and machinery and, as the object of this study, natural resource capital. It is composed of those facilities, improvements and equipment acquisitions associated with irrigation, drainage and soil conservation activities.

Investment Related to Capital

Start with production during a specific interval of time, initially considering only consumers and the business sector. This production consists of all the newly available goods and services for which participants (and production factors) in the provisioning process earned some income. The value of the total output is figured as the total income thereby earned. Subtracting from the total output and income the goods and services actually purchased by consumers leaves two important items: (a) newly available but unsold consumer goods; and (b) newly available business goods not intended for individual personal consumption, like industrial plants and office buildings, all types of machinery and production equipment, ships, airplanes, water supply facilities, pipelines, etc. Their use normally extends over a very considerable period of time.

The final satisfactions and any added income-yielding benefits inherent in (a) and (b) are obviously deferred to the future. Items (a) and (b) thus constitute 'investment' (13). Investments of type (b) are of particular interest for capital growth analysis. They will cause the net stock of capital as discussed previously to increase if they more than make up for depreciation--the wearing out of existing capital. This is why depreciation is alternatively called capital consumption.

These ideas about investment are behind conceiving of the gross national product or income (GNP) as simultaneously divisible into and arising from expenditures for personal consumption (C) and expenditures for gross private domestic investment (I), apart from the government purchases (G) and export components of national output (E). The consumption/investment dichotomy is present also in the government and trade sectors because, for example, as financed from taxes (government income), government purchases may be for personal services and expendable supplies. These are consumption items for the government.

On the other hand the government purchase may be acceptance of a contractor's bid to build a reservoir for an irrigation and flood control project. This is not current consumption but investment made by society, by proxy through its government.

Also for a defined economy the total amount of investment that actually occurs over a prescribed period of time will be balanced by the total saving that occurs (14). This does not mean that saving and investment are the same thing. Aggregate saving has four primary parts: (a) Personal saving, as decisions of individuals to not consume all their current personal income, (b) depreciation set-asides in agriculture and other businesses, (c) undistributed corporate and

other heldback profits, and (d) the so-called government surplus or deficit. Government can and will save for a society if its total collections of income, excise or other taxes, plus private payments into any social insurance programs, exceed total government outlays for goods and services, social program benefits, and grants and other transfers, either at home or abroad.

As explained before, total investment during the same period will show up either as (a) expenditures for new homes, office buildings or industrial installations and equipment, (b) changes in business inventories, or as (c) an excess of exports over imports (less drains of income to foreigners to be exact). This recognizes, for example, that a dairy farmer setting up facilities for raising new dairy stock is investing in the very same sense as someone else building a new lumber franchise. The investment outlays in both cases add directly to national production and become part of the national income. Likewise, a net export balance increases national income and is counted as part of total investment for the exporting country. This does not mean that a nation's economic interests are necessarily served best by maximizing exports over imports.

To summarize, production and income generation are continuous processes. The essential objects of investment are to maintain and increase the capacity to produce goods and services, thereby producing income. In accounting for part of aggregate income, investment is also continuous. Continuous processes are measured as rates per year, quarter, month, etc. In short, investment is a flow concept because income is a flow.

On the other hand accumulated investments become stocks, much like an irrigation reservoir creates a stored supply (or stock) of water by impounding streamflow. This means that any constructed or manufactured capital asset, whatever its purpose and form, is usefully regarded as embodying prior investments and sacrifices in consumption as well as possibilities for future production.

Theoretically and in the real world the present (discounted) value of the future productivity of physical assets is the cash their sale to others would produce, presuming the existence of a suitable formal market or other mechanism for completing such a transaction. This is the concept of net capital value adpoted in this work. Values are also net in the sense that market prices, whether known rather definitely or only inputed, are presumed to reflect buyer and seller discounts for losses in original value due to depreciation, damage and obsolescence.

Measuring Capital Stocks and Net Values

What is the process by which empirical estimates of capital values can be obtained, when in the case of many natural resource assets, distinct conventional markets do not exist?

Perpetual inventorying is the general approach used here (15). It conceives of gross investment in year j, called A_j, as being divided into two parts: the part necessary to make up for depreciation on capital assets already existing, called D_j, and the part permitting the creation of new facilities, called Q_j. Gross annual investment need not be at least equal to depreciation or anything else (except gross saving), because gross investment occurs as investors

decide on their own particular expectations of money profits and other benefits. Gross investment is thus independent of depreciation. Net investment is gross investment less depreciation. Gross investment over n periods is termed A_n (= ΣA_j, j = 1, 2, . . . n).

Capital can then be regarded as the accumulation of past investments which created new physical assets, minus those assets that have been used up and discarded. In practice, the capital stock is measured most realistically at two levels. The gross capital stock, called K_n, still existing after n years or similar accounting periods, is the total gross investment to date, A_n, minus the capital assets retired to date, called T_n. The net capital stock, Q_n, is the remaining net value of all capital still in use. Q_n is estimated as accrued gross investments A_n, minus accrued depreciation D_n, and also minus any assets sold off as salvage, pT_n. Let the fraction p be the average proportionate salvage value of the assets thus far retired. This means that accrued gross investment A_n can be balanced and accounted for in two ways:

$$A_n = K_n + T_n, \text{ and } K_n \text{ (gross capital stock)} = A_n - T_n \qquad [1]$$

$$A_n = Q_n + pT_n + D_n, \text{ and } Q_n \text{ (net capital stock)} = A_n - pT_n - D_n \qquad [2]$$

To calculate the net value of the capital stock still in use, deduct pT_n for salvage. This recognizes that, once retired, prior investments are no longer depreciated but go into the salvage account.

The remaining specific connections between annual investment, capital retirement, salvage, and gross and net capital stocks are shown in equations 3 to 10 (16). The subscript j refers to individual time periods, usually years, and n refers to a given number of periods to date. The term p is the proportionate salvage factor after u years of useful service life. The term d is the annual depreciation rate if the constant-percentage depreciation method is used.

$$A_n = \text{gross investment over } n \text{ years} = \Sigma A_j,\ j = 1, 2, \ldots n \qquad [3]$$

$$T_n = \text{capital retired over } n \text{ years} = \Sigma T_j, \text{ with} \qquad [4]$$

$$T_j = \text{capital retired in year } j : T_{j<u} = 0; T_{j>u} = A_{j-u} \qquad [5]$$

$$K_n = \text{gross capital stock after } n \text{ years} = A_n - T_n = \Sigma (A_j - T_j) \qquad [6]$$

$$pT_n = \text{capital salvage over } n \text{ years} = \Sigma pT_n \qquad [7]$$

$$D_n = \text{depreciation over } n \text{ years} = \Sigma D_j, \text{ with } D_j = d\, Q_{n-1}, \text{ where} \qquad [8]$$

$$d = \text{depreciation rate, constant-percentage method} = 1 - p^{1/u} \qquad [9]$$

$$Q_n = \text{net capital value after } n \text{ years} = A_n - pT_n - D_n = \Sigma Q_j \qquad [10]$$

In this study the perpetual inventory model could be abbreviated in two ways. Completely depreciated irrigation, drainage, and conservation improvements and equipment were considered to have negligible salvage value and the straightline method of depreciation was used. This means that the term pT_n could be omitted

from equation 2 and equation 7 dropped entirely. Revised equations 8 to 10 then appear as:

D_n = depreciation over $\underline{n}$ years = ΣD_j, with $D_j = d\ K_{n-1}$, where [8r]

$\underline{d}$ = depreciation rate, straight-line method = $1/u$ [9r]

Q_n = net capital value after $\underline{n}$ years = $A_n - D_n = \Sigma Q_j$ [10r]

Note an important difference between the initial and revised capital inventory models. If depreciation as capital consumption is determined by the constant-percentage method, then the constant depreciation rate (equation 9) is applied against the previous year's closing <u>net capital value</u>, as in equation 8. If the straight-line depreciation method is used, the depreciation rate remains a constant fraction (equation 9r). But 9r is applied against the previous year's closing <u>gross capital stock</u>, as in equation 8r.

In the perpetual inventory model changes over time in the purchasing power of the dollar are allowed for by deflating all gross investment rates to constant dollars, that is, to the price/cost levels prevailing in some base year, selected here as 1977. When deflated the gross and net stocks can be interpreted the same way as physical magnitudes and directly compared with labor and other inputs and correlated with production quantities or similarly deflated production values. The cost of obtaining all existing assets as base-year prices is the real gross stock of capital.

The real net stock is the depreciated value of the real gross stock, allowing for the fact that existing assets have depreciated to various degrees through use, unforeseen damage, and perhaps obsolescence. By implication, net stock values also reflect the net benefits from future productive services inherent in the existing assets. The net values imply a price at which the assets might be sold in a market setting, recognizing that distinct markets do not exist for most types of natural resource assets, especially those salable only as part of real estate. Changes in net capital values constitute net capital formation.

A more detailed explanation of perpetual inventorying as applied in this research and keyed to some actual results is in appendix B.

COMPOSITION OF NATURAL RESOURCE CAPITAL

The perpetual inventory method is an efficient way to develop capital-stock estimates from historical investment rates. The next step is to specify empirically the measurable irrigation, drainage, and conservation components of capital.

<u>Irrigation Capital</u>

Irrigation facilities include: land improvements made to permit irrigating, such as farm ditches and land leveling; durable irrigation equipment such as pumps, power units, and sprinkler systems; and irrigation water-supply, storage, or distribution works, such as wells, ponds, and reservoirs, regardless of where located and by whom financed. These facilities include major works of a project

nature as well as those on farms and ranches, whether used for gravity or sprinkler-irrigation systems, and whether financed by the Federal Government, irrigation organizations, or individuals.

Gravity Irrigation Systems

Gravity irrigation facilities include: Open and covered canals and conduits, from which water is carried to fields in supply ditches and then turned directly or siphoned into furrows; underground piping from water sources with turnout valves for each major point of field supply; and piping directly from water sources, usually to nurseries, greenhouses and truck crops. The water may be pumped from wells and streams or drawn from streams and reservoirs at points higher than the area to be irrigated. Some irrigation operations, mostly nurseries, use public water systems.

Sprinkler Irrigation Systems

In sprinkler irrigation water is discharged under developed (gauge) pressure through perforated pipe, stationary sprinklers, rotating sprinklers, and various types of nozzles and tubes. Pressure systems are generally regarded as permanent, semiportable, or portable according to needs for moving the distributing equipment, without necessarily changing the pump or water source. Five present principal variations are: permanent installations and solid-set portables, portable systems moved manually, towed or mobile equipment other than self-propelled center-pivot (CP) systems, CP systems, and drip irrigation systems.

Federal Irrigation Capital

The net Federal capital in irrigation facilities, calculated as cumulative gross Federal investment minus cumulative depreciation allowances, is the net value of that portion of U.S. Bureau of Reclamation (USBR) investments in project property, plant, and equipment reasonably allocable to irrigation in multipurpose projects, or to single-purpose irrigation projects as such. Project rehabilitation and betterment expenditures were considered to represent depreciation (17). Details and comparisons of irrigation with other authorized multipurpose development activities of USBR are in notes (18) and (19).

For years following 1944, part of the net capital value of Federal irrigation investments (a peak of 3 percent in 1970) was accounted for by Federal cost-sharing for certain approved onfarm land preparation improvements under the Agricultural Conservation Program (ACP). Since 1957, The Great Plains Conservation Program (GPCP) also authorized some limited Federal cost-sharing for land preparation in connection with irrigation.

Non-Federal Irrigation Capital

Non-Federal irrigation capital includes: Independent private investments in onfarm irrigation improvements and facilities from 1870 to 1980, including farmer purchases of irrigation equipment; additional onfarm facility and land preparation investments made between 1936 and 1980 under the ACP cost-sharing program; investments in group irrigation facilities made by State agencies and irrigation organizations from 1870 to 1980, excluding those facilities

constructed and still owned by USBR; irrigation features of structures installed since 1954 under the Watershed Protection and Flood Prevention Act; and some private irrigation investments made since 1956 under cost-sharing provisions of the GPCP.

Drainage Capital

Drainage capital includes: Depreciable land improvements made to carry excess water from fields, either to facilitate tillage or increase usable land and productivity, either with surface ditching or with buried tile, plastic, and other subsurface drains; durable equipment needed for drainage, such as pumps, and power units; and any other collection and durable disposable works like sumps, collection ditches, levees, and other facilities, regardless of where located. All drainage investments on farms are included, whether made with or without Federal cost-sharing under the ACP.

In this study those major drainage investments connected with irrigation projects, or later made necessary because of sustatined irrigation, are considered part of irrigation capital rather than drainage capital.

Conservation Capital

Conservation capital includes: Depreciable onfarm land treatment and management measures designed to reduce soil loss from water and wind erosion, including permanent vegetative cover establishment, stripcropping, terracing, diversions, and shelterbelts; sod waterways and various detention structures for sediment reduction and water quality control; and water impoundment structures for flood prevention, erosion, and water quality control. Some of these may jointly provide fire protection, livestock water, and water to irrigate permanent vegetative cover.

All conservation investments on farms are included, whether publicly or privately funded. The measures and structures for which Federal cost-sharing assistance was given under the ACP and GPCP must be permanent and maintained at least 5 years. They may have either an onsite soil conservation or general environmental improvement orientation. Official ACP, GPCP, and other USDA agency records were the main source of Federal cost-sharing information (20).

Federal investments for watershed protection under the Watershed Protection and Flood Prevention Act (P.L. 83-566), and also in the so-called Flood Prevention Watersheds are represented by the Federal obligations of appropriated funds (21). Non-Federal and local inputs for planning, easements, and other construction contributions were estimated to be 17 percent of the Federal investments. This percentage was based on 1,120 individual watershed work plans inventoried for costs and benefits by the Economic Research Service (22).

Although irrigation and drainage investments connected with ACP, GPCP, and various watershed programs are sometimes described as conservation, in this work they are included only under irrigation or drainage capital.

PROCEDURAL DECISIONS AND ASSUMPTIONS

Perpetual inventorying is useful as an overall guide for capital stock measurement. In practice its applicability depends on the kind of appraisal situation represented by each type of irrigation, drainage, and conservation asset, and particularly on the specific manner in which such assets depreciate.

General Problems of Estimation

This study of natural resource capital growth followed the historical research method. The historical approach precluded the option of evaluating changing investment rates via systems of formulas like those commonly emphasized in the literature on financial appraisal. In textbook presentations, investment and depreciation are nearly always either constant or expressed as mathematical functions of time. Such a 'formula approach' is applicable primarily to projective appraisals of capital growth based on constant or systematically changing rates of investment, depreciation, and related technological and institutional assumptions. All of these are subject to varying degrees of uncertainty and probable error.

An historical analysis of NRC growth, however, does not eliminate uncertainty and measurement difficulties. First, official records of investment in irrigation, drainage, and conservation are intended to serve legislative, public-information, and administrative rather than research purposes. Research classifications had to conform to these realities as well as recognize the usual differences in the quality and completeness of historical records.

Project Irrigation and Drainage Facilities

Depreciation on project facilities was not calculated by any formal method against existing capital values but rather was treated as a deduction from gross annual investment. The Bureau of Reclamation (USBR) and most other irrigation and drainage organizations do not maintain depreciation accounts, mainly because of the intended permanence of their facilities and the particular legislative conditions under which they function. The proxy for depreciation of USBR irrigation facilities was the investment in rehabilitation programs (17). From 1903 to 1948, USBR rehabilitation expenditures were quite minor and not a specific line item in agency budgets. So for the purposes of this work, gross and net stock values, as cumulative construction appropriations for USBR irrigation works and equipment, were considered the same between 1903 and 1948 (24).

For project irrigation facilities other than those owned by the Bureau of Reclamation, and for all project drainage, the measure for depreciation was the portion of gross annual investment reported since 1870 in the Censuses of Irrigation, Drainage or other documents that was used to replace existing facilities rather than for building new facilities. The reasoning here was that rehabilitation and replacement costs impose a demand on annual investment budgets but create no new capacity. Formally-calculated depreciation has an analogous meaning.

Operation and Maintenance (O&M) accounts were considered but discarded as suggestive of depreciation. Typically there is no effort for project

organizations to separately budget the two components. As the bulk of the expense is for operations as such, latent errors in the capital stock values developed herein are probably minor.

Maintained public drains were depreciated to a minimum of 50 percent of their original cost over a period of 60 years, and then held constant in net value (table 21). Their gross stock value indefinitely remains the same as their original real cost.

Onfarm Irrigation and Drainage Facilities

Onfarm irrigation facilities include land leveling or other field preparations, wells, ponds, stream-diversion works, turnouts, ditches, and so forth; that is, any durable feature of a farm irrigation system other than durable equipment. Equipment as such is discussed below. As to assumed service lives (table 21), onfarm gravity irrigation systems were assigned an average useful life of 20 years with normal maintenance and depreciated by the straight-line method.

Onfarm surface drainage improvements were assigned an average useful life of 20 years with no salvage value and then depreciated at a straight-line rate. Subsurface drains installed before 1940 were assigned an average useful life of 30 years. Those installed after 1940 were assumed to last 40 years.

Some of these assumed useful lives for onfarm irrigation and drainage facilities may appear unduly short. However, they recognize that income tax regulations permit accelerated depreciation of irrigation and drainage works and thereby encourage 'premature' replacement with improved systems and materials.

Farmer-Owned Irrigation Equipment

This category includes items like pumps, power units, pipe, siphon tubes and various components of farm sprinkler irrigation systems. A special analysis of sprinkler irrigation equipment investments since 1940 was necessary to construct an original time series on irrigation equipment stocks in general. While straight-line depreciation was assumed on all types of irrigation equipment, assumed useful lives varied according to the particular equipment or associated water-supply improvement involved. See table 21 and note (25).

Land and Environmental Conservation

No acreage series were constructed for conservation measures (26). As for irrigation and drainage facilities and equipment, annual current-dollar private and governmental investments in farm conservation and watershed land protection were first converted to constant dollars, then summed to obtain gross capital stocks (allowing for retirements), and then depreciated to obtain the net capital values. Ordinary maintenance was regarded as an operating cost and not included as part of gross investment. But major or nonordinary maintenance frequently occurs as substantial improvements and supplementary treatments. These may again qualify for Federal cost-sharing. Such re-application expenditures are incorporated in annual conservation investments and also depreciated.

Service lives for straight-line depreciation purposes varied primarily according to the type of conservation measure or structural improvement involved, guided partly by the legislation authorizing joint Federal and private financing; e.g., cost-sharing (table 21). Conservation measures administratively regarded as 'temporary' were excluded altogether. Service lives assumed for permanent conservation land treatment measures ranged between 25 years if installed under the Agricultural Conservation Program to 30 years if installed under the Watershed Protection and Flood Prevention Act of 1954 (P.L. 83-566). If installed under the Great Plains Conservation Program, authorized in 1956, permanent conservation measures were also assigned an average useful life of 25 years. All water-supply structures for land protection, irrigation or drainage installed under the P.L. 566 program or in the 11 Flood Prevention Watersheds authorized in 1944 were assumed to have a 50-year service life (27, 30).

GENERAL RESULTS

The main concerns in this study were the quantification of natural resource capital (NRC) and its historical growth, both by itself and in relation to the traditional fixed capital items like buildings, producer equipment, and farm vehicles. Quantification was achieved by analyzing historical gross investment, depreciation, and net investment separately for the different types and modes of financing for irrigation, drainage, and conservation assets.

Changes in Major Classes of Farm Capital

The changing role of natural resource capital (NRC) and other forms of farm business capital within the farm economy since 1900 is shown in table 1. Figures 4 to 7 are the related charts. NRC is part of fixed physical capital in agriculture, along with producers' durable equipment, residential structures, and service structures. Livestock and crop inventories are also physical capital. As in other sectors of the economy, annual changes in farm inventories are an element of gross private domestic investment. The largest category of farm physical capital is land. The values for land in table 1 and figures 4 and 5 are aggregate farm real estate values in constant 1977 dollars less the value of farm homes and farm service structures.

In 1980, land accounted for two-thirds of non inventory business capital (table 1, col. 6). Except for the period 1920-40, the importance of land relative to depreciable capital has declined, from about 95 percent of all physical farm capital in 1900 to about 67 percent in 1980. Farm business inventories, mostly livestock and livestock feed supplies, have grown moderately but steadily. Between 1900 and 1980, farm business inventories increased in net value by an almost constant 1.1 percent each year, rising from 7 to 11 percent of farm physical capital.

Depreciable capital is the most variable and substituted component of real physical capital in agriculture (table 1, col. 7). Its growth and decline since 1900 closely parallel economic conditions generally prevailing at the time, such as disinvestment through the farm depression of 1920-35, followed by recovery, especially in the years immediately following World War II. In the interval 1931-35, the net value of durable equipment and nonresidential farm structures

declined an average of $1.9 billion per year. The rebound from 1946-50 was $5.3 billion per year (table 1, figure 6).

Natural Resource Capital

Net values for NRC assets capital as of the year 1980 appear in table 2, in the aggregate and separately for irrigation, drainage, and conservation. Figures 8, 9, and 10 show natural resource capital formation in the aggregate, followed by historical investment rates and capital values for irrigation, drainage, and conservation.

In 1980, irrigation, drainage, and conservation facilities and associated equipment had a combined net depreciated real value of $44.3 billion (tables 1 and 2). NRC thus represented about one-fourth of all fixed nonland capital in agriculture. The $44.3 billion in net NRC value for 1980 was made up of about $23.7 billion for irrigation (53 percent), $7.5 billion for drainage (17 percent), and $13.1 billion for conservation (30 percent).

As of 1980, the Federal Government, through direct construction or indirect cost-sharing, had created about 45 percent of the net value of all NRC in the United States, varying from 4 percent for drainage to 46 percent for both irrigation and conservation (table 2). The overall Federal involvement was greatest during the Depression and World War II. It focused mostly on farm conservation and irrigation projects, particularly those irrigation water storage projects where hydropower capacity could also be obtained (figure 41). Significant cutbacks in Federal conservation and irrigation development eforts have occurred since 1965 (figures 42 and 43).

As of 1980, group or project works accounted for about 60 percent of the net capital value of water management facilities, whether for irrigation or drainage (table 2). During the same period, project improvements accounted for about 25 percent of net capital values for conservation. Project works can be either privately, publicly, or quasi-publicly created and/or owned.

AGRICULTURAL IRRIGATION

The origins of irrigation in what is now the United States cannot be dated precisely because irrigation in world cultures is undoubtedly almost as ancient as agriculture itself. According to Golze', irrigation was practiced on a community basis with impressive canals built by Pueblo Indians at least as early as A.D. 800, in what is now New Mexico and southern Colorado (64). He traces irrigation in the United States to three separate influences: (1) native Indian developments; (2) the more advanced practices of Spanish conquerors, missionaries and colonists coming from Mexico and Spain; and (3) the at first crude but soon perfected methods employed by settlers coming from the eastern United States, notably the Mormons, who migrated from Illinois to Utah in 1847.

According to Golze' and also Huffman, the next major historical event was the Greeley Colony in Colorado. It was established by Horace Greeley and his assistant Nathan Meeker (64, 65). Greeley was publisher of the New York Tribune and espoused many causes, including the abolition of slavery. He is the person usually associated with the famous piece of free advice, "Go West, young man, go

West". (According to the New Standard Encyclopedia, Greeley actually borrowed this slogan from a newspaper in Terre Haute, Indiana.)

A number of other private irrigation enterprises, notably the Anaheim and Riverside Colonies in California, were also started in the 1870's. They were encouraged in part by the Homestead Act of 1862. However, the Desert Land Act (1877), the Carey Act (1894), and the Reclamation Act (1902) are the principal Federal laws designed to facilitate irrigation development and settlement in the arid West.

The first U.S. Census involving irrigation was taken in 1890. It covered the year 1889. In those two years six western States had been admitted to the Union. Washington, Montana, North Dakota and South Dakota joined in 1889, followed by Idaho and Wyoming in 1890. In 1889 about 3.6 million acres of irrigated crops and pastures were irrigated on 52,000 farms in the 11 far western States or Territories.

In the decade 1889 to 1899, irrigation more than doubled--to 7.3 million acres, on 103 thousand farms. The 1899 acreage was distributed as follows: Colorado (1.6 million acres); California (1.4 million acres); Montana (950,000 acres); Utah (630,000 acres); Wyoming (605,000 acres); Idaho (600,000 acres); Nevada (505,000 acres); Oregon (390,000 acres); New Mexico (205,000 acres); Arizona (185,000 acres); and Washington (135,000 acres). This listing gives the approximate distribution among States of the 7.7 million-acre national total for 1900 shown in table 3 and figure 11.

For easy comparison and later reference the information on acreage, investment and capital stocks for irrigation is consolidated in tables 3 to 11 in appendix B, also in figures 11 to 24 in appendix C. Census and other records going back to 1870 were used (31, 33, 34).

Long-term information on irrigation is given for every fifth year starting with 1900 and ending with 1980. For example, table 3 and figure 11 give the acreages irrigated with and without project facilities for decade and mid-decade years. Table 4 and figure 12 show the division of these aggregate acreages over time between gravity versus sprinkler irrigation. Tables 5 to 11 (also figures 13 to 19) give average annual investment rates, acreage change rates, and the periodic status of capital values for project verus onfarm irrigation assets. Per-acre capital inputs and marginal irrigation costs are estimated and explained in tables 9, 10, and 11. Figures 20 to 24 are corresponding marginal cost diagrams.

While nonagricultural irrigation could not be covered in this study it merits equal research attention. Irrigation is an almost universal requirement for residential lawn care and also for maintaining parks, golf courses, cemeteries and business properties.

The following discussion of the extent, economic importance, and changing technology of farm irrigation will help put the subsequent investment and capital status information in better historical perspective.

Current Extent and Importance

The definition of agricultural irrigation adopted herein is from the U.S. Bureau of the Census: "Irrigation refers to the application of water, by artificial means, to land being used for agricultural purposes. These artificial means include subirrigation as well as application of water to the ground surface either by general flooding, by basins, and by furrows, or less directly through the use of sprinklers". (U.S. Bureau of the Census, U.S. Census of Agriculture: 1959. Vol. III, Irrigation of Agricultural Lands (1962), p. xix).

Extensive information on the physical and economic principles involved in irrigation, different irrigation systems, types of installation equipment, and materials used is available in Monograph No. 11 of the American Society of Agronomy, also in Monograph No. 3 of the American Society of Agricultural Engineers (25). Drainage needs in conjunction with irrigation are discussed by Luthin, Donnan, Ochs and others (40c, 43, 44, 50). Lea has recently compiled a detailed set of irrigation statistics by regions and States for the 1978 Census year, including crops irrigated, sources of water, and methods of water application (66).

Irrigated Acreage, 1982

The final 1982 Census of Agriculture was released in 1984. It and other sources indicate that 54.5 million acres of agricultural land were irrigated in the United States in 1982. The geographic location of U.S. irrigation is shown in figure 1. The average was 176 acres per farm irrigating. Around 278,000 or 12 percent of all U.S. farms reported irrigation in 1982. About 5.5 million acres of the land irrigated was either in pasture or other noncroppped land. The 49 million acres of irrigated land from which crops were harvested came to about 14 percent of all cropland reported harvested in the United States.

In 1982 there were 14 States with at least a million acres of farmland irrigated, according to the Census Bureau. Ranked by millions of acres irrigated, these States were: California (8.6), Nebraska (6.0), Texas (5.5), Idaho (3.5), Colorado (3.2), Kansas (2.7), Montana and Arkansas (2.1), Florida (1.6), Oregon (1.8), Washington and Wyoming (1.6), and Arizona and Utah (1.2). In addition, Nevada had 830,000 irrigated acres. Practically all cropland in Nevada and Arizona is irrigated. In 1982 New Mexico also had about 700,000 acres irrigated, amounting to 55 percent of its harvested cropland. Hawaii had 146,000 acres irrigated--76 thousand acres in crops and 70,000 acres in pasture. The 17 States highlighted here had nearly 90 percent of the farmland irrigated in the United States in 1982.

The intensity or dependence factor is also important. States where more than the national percent (13.6) of the harvested cropland was irrigated in 1982 form a rather different ranking: Nevada (100 percent), Arizona (99 percent), California (89 percent), Utah (73 percent), Wyoming (63 percent), Idaho (62 percent), New Mexico (54 percent), Hawaii and Florida (49 percent), Colorado (44 percent), Oregon (42 percent), Nebraska (34 percent), Washington (28 percent), Arkansas (27 percent), Texas (25 percent), and Montana (17 percent).

Area Irrigated in 1980

From various Censuses, plus industry and other information sources, the amount of land irrigated on U.S. farms in 1980, the terminal record year for this study of natural resource capital formation, was estimated to be about 54 million acres (table 3 and figure 11). Another 5.4 million acres, the bulk of it within organized irrigation projects, were also irrigable with facilities in place but for various water supply and other reasons were not actually irrigated in 1980.

Economic Production Significance

The Censuses of Agriculture and of Irrigation Organizations also contain statistics on the importance of irrigation in the economies of States and counties. For the United States as a whole, about 22 percent of the value of all farm crops and livestock products sold in 1982 (in 1982 dollars) came from irrigated farms. Crops represented about two-thirds of the gross sales from irrigated farms. Livestock products represented one-third. In 1982 the 278,000 U.S. farms having at least some irrigated land represented 12 percent of all U.S. farms. But the irrigated farms accounted for 43 percent of the value of all crops marketed and also for 19 percent of all livestock products sold.

The economic dependence of agriculture on irrigation varies widely among individual States, even those in the arid West. In Nevada, for example, the 1982 Census showed that 100 percent of the value of all crops, and also that 86 percent of the value of livestock products sold came from irrigated land.

In the important livestock State of Wyoming, livestock account for 88 percent of gross farm receipts and crops for 12 percent of the receipts. But 70 percent of all receipts come from the 8,900 farm or ranch units that include at least some irrigated land. The irrigated farms contribute 83 percent of the crop receipts and 75 percent of the livestock product sales. The fact that even the highly irrigated farms (all crops irrigated) obtain 75 percent of their gross income from livestock sales shows that Wyoming irrigation is oriented very strongly to the State's livestock economy.

Acreage- and dollar-wise, the leading irrigation State is easily California. In 1982 it had at least 8.5 million acres of irrigated land--17 percent of the U.S. total. About 82 percent of California's crop and livestock products sold (totaling $10.3 billion in 1982) came from its 58,000 irrigated farms. About 48,000 farms in California irrigate all their crops. These highly irrigated farms market 91 percent of California's crops and nearly half (45 percent) of the crops sold from all U.S. farms where crop production depends entirely on irrigation. California alone produces about a fourth of all crop and livestock products marketed from the 278,000 farms in the United States that include irrigated land. The total sales from such U.S. farms in 1982 came to about $39.7 billion or 30 percent of the aggregate value of all farm products sold.

Acreage-wise the second irrigation State is now Nebraska (6.0 million acres), having recently displaced Texas (5.5 million acres). In 1982 about 62 percent of Nebraska's farm products sold (totaling $6.6 billion) came from its 22,000 irrigated farms. Irrigated farms accounted for 70 percent of all crops and 58 percent of all livestock products sold from Nebraska farms. For the irrigated

farms, crops accounted for 40 percent of the receipts and livestock products for 60 percent of the receipts.

Two eastern States where crop production is heavily dependent on irrigation include Florida and New Jersey. The 83,000 acres of irrigated land in New Jersey are used almost exclusively for truck and nursery crops. Over 70 percent of the crops sold in New Jersey are produced on irrigated land. Slightly over half of the irrigated crops came from farms that rely entirely on irrigation. In this generally urbanized State, land values per acre for these farms run about 20 percent greater than for the farms not irrigated.

In Florida (1.6 million acres irrigated) the 11,000 irrigated farms out of the State's 36,000 farms account for 71 percent of all farm products sold but for 89 percent of all fruits, vegetables and other crops sold. Further, nearly a fourth of the livestock, dairy and poultry products marketed from Florida come from irrigated farms. Per-acre land values for farms highly irrigated run nearly 90 percent above those for farms not irrigated.

Long-Term Acreage Shifts

Several important continuing changes in irrigation have occurred since just before World War II. One is a decreasing reliance on project water supply facilities. While this change became quite pronounced in the 1950's, the process appears to have been in motion even during the Depression years (see table 3).

Two somewhat related shifts began about 1955. One was greater dependence on ground water and the importance of aquifer management, even on some major irrigation projects first designed for streamflow diversion and reservoir storage. Many of the independent farm irrigation systems installed in the 1950's pumped ground water entirely, most notably in the High Plains of Texas, Oklahoma, New Mexico and Colorado, some areas in California, and in Nebraska and Kansas.

The second change in the 1950's was the development of aluminum irrigation tubing and quick-couplers. Because of the need for aircraft and other war material, aluminum production capacity had been increased tremendously since just before World War II. Sprinklers made the irrigation of much more land feasible from the topographic, technologic, and economic, (including labor-saving) standpoints. This was true within established and new projects as well as for independent farm systems. Drought in many eastern States at the time provided an immedaite and further impetus for irrigation in normally humid areas.

Regional and State Shifts

Irrigation in the United States has continued 'moving' toward the humid States, despite relative stability or continuing expansion in most of the western States. Decreases have occurred in Texas, Oklahoma and New Mexico. The relative movement eastward continued between the 1978 and 1982 Censuses. From 1978-82 there was about a 2.7-percent national net decrease in irrigated land. For the western States the average decrease was 4.4 percent, but most of this

decline was in Texas. In 1974 the humid East had only 9 percent of the irrigated land. By 1978 this share had increased to 14 percent; in 1982 it had grown to 16 percent.

Of the western States only the Dakotas and Nebraska showed increases in irrigated land between 1978 and 1982. Decreases were nearly 20 percent in Texas, 9.3 percent in New Mexico and 8.1 percent in Arizona. Large increases continued in some eastern States, but nearly 80 percent of the 1978-82 gross acreage gain for the humid region as a whole can be ascribed to gains in five States. Their shares of the total gain in the East were: Arkansas (39 percent), Mississippi (14 percent), Georgia (13 percent), Michigan (6.7 percent), and Indiana (6.5 percent). A significant decrease was registered in Florida, down 20 percent from the 1.980 million acres irrigated in 1978.

Project and Nonproject Irrigation

Acreages of farm irrigation depending and not depending on project facilities over the period 1900 to 1980 are given in table 3. The corresponding time graph is figure 11. An emphasis on project development, excluding Bureau of Reclamation projects, actually began to weaken between 1935 and 1940. In 1935 about 12 million acres were irrigated within project service areas--about 91 percent of all land then irrigated. By 1940 the project acreage had increased to 13.2 million acres, but by then this was then only 73 percent of all land irrigated. A qualifying observation here is that much of the private gain from 1935 and 1945 probably involved pasture flooding from small stream diversions, a form of irrigation not requiring heavy capital expenditures.

A modest new interest in project irrigation developed after World War II and continued until about 1965. By then the share of irrigated land served by projects (19.4 million acres) had fallen to 51 percent of all irrigation, because independent farm installations had expanded more rapidly. For example, in the immediate postwar period (1946-50), the area irrigated within projects other than those constructed by the Bureau of Reclamation (USBR) fell by 1.2 million acres. The area served by USBR projects increased by 915 thousand acres, while the area irrigated privately increased by 5.5 million acres. As of 1980 almost 60 percent of all the land irrigated in the United States did not depend on project water development. About 90 percent of the land newly irrigated between 1976 and 1980 did not depend on project water supplies (table 3).

These national changes are important but it is vital to recognize that nearly half (48 percent) of the irrigated land in the 17 western States still depends for water on nonprofit public irrigation facilities built by such entities as the Bureau of Reclamation (USBR), Corps of Engineers, Bureau of Indian Affairs, and State agencies or irrigation districts, or what the Bureau of the Census calls "irrigation enterprises."

To emphasize this point further, in Utah nearly all irrigation still depends on project water. Other States where at least half the land irrigated still depends on project water include: Nevada (87 percent), Montana and Wyoming (80 percent), Idaho (75 percent), Colorado and Washington (70 percent), California (67 percent), Oregon (55 percent), New Mexico (54 percent), and Arizona (50 percent).

Given these qualifications some explanations are warranted on the apparently accelerating national decline in project irrigation relative to independent farm irrigation systems.

1. Over the years since large-scale project irrigation in the United States began (circa 1870), most of the farmland depending for irrigation water on large-scale community and public efforts has been developed;

2. The technology of onfarm irrigation has been improved to the extent that more farmers can install and operate their own systems without hiring much if any labor, and also using improved materials, modern equipment, and the technical services of local service companies and public agencies;

3. For some years, actually since the 1930's, there has been a decided reversal of the initial policy of the Federal Government to build single-purpose irrigation works, toward multipurpose environmentally compatible projects jointly including navigation, hydropower, flood control, urban water supply, recreation, and so forth.

These limiting factors in irrigation project development are partly offset by recognizing that much new investment in farm irrigation will doubtless replace existing systems that do use project works. Also, while the national trend over the past 40 years toward larger and fewer farms implies somewhat more freedom for owners and operators to irrigate independently of other farms, enlarged farm units may well encompass land already irrigated using existing project works. Moreover, one cannot infer that what is reported as a large acreage of irrigated land for Census purposes is one block of land, although such an inference may be a bit more valid for project than for non-project irrigation.

Another factor is that the need for cooperative water supply management tends to increase with the number of individual irrigation systems within a given area. The success of irrigation is determined by water availability, climate, soils, topography, and other physical conditions, as well as by economic and sociological considerations. Thus, significant new cooperative irrigation activity, some requiring expensive water storage, distribution and groundwater recharge works, has been stimulated by increasingly complex community water management problems.

Gravity and Sprinkler Irrigation on Farms

Of the 54 million acres of farmland irrigated in the United States in 1980 about 35 million acres (65 percent) were irrigated by so-called 'gravity' methods, including flooding, ditches, gated pipe, and various combinations thereof. The remaining 19 million acres (35 percent) were irrigated with sprinkler systems (tables 2 and 5). About 10 percent of the irrigators use both gravity and sprinkler systems.

Figure 12 shows how sprinkler irrigation has increased geometrically since 1940, even though, acreage-wise, gravity irrigation increased much more rapidly until about 1960. The 5-year acreage change rates in table 4 show this even more clearly. Dramatic gains in sprinkler relative to gravity irrigation since 1960

can be attributed in part to larger and improved mobile and self-propelled sprinkler systems requiring a minimum of supervisory and field labor. Improvements have also been made in gravity irrigation.

More complete information on how the technology of sprinkler irrigation has itself changed rapidly can be obtained from table 11. Part A summarizes investment, acreage-increase rates, and related economic data by 5-year periods from 1920 to 1980.

Parts B and C are a breakdown of total sprinkler irrigation investments and capital values into the water supply and pumping components versus all kinds of water distribution systems. The remaining parts of table 11 apply to particular broad types of distribution systems, such as permanent/solid sets (part D), hand-moved arrangements (part E); towed, rolled or similarly portable systems (part F); self-propelled other than center-pivots (part G); center-pivot systems (part H); and finally 'drip' systems (part I).

The first important sprinkler systems, largely found in orchards, nurseries and on truck farms, were almost exclusively permanent installations. In 1980 permanent systems still accounted for about 9 percent of the acreage sprinkler irrigated and for 17.6 percent of the net capital in all sprinkler types.

Hand-moved systems became important after World War II. By 1950 they were used on 44 percent of the acreage sprinkled and made up 19 percent in the net capital value of all sprinkler types. In 1980 hand-moved systems covered only 19 percent of the sprinkled acreage and, because of depreciation, had declined to virtually zero net book value. However, they still represent about 10 percent of the replacement value of all sprinkler systems now in use.

By 1975 center-pivot systems (CP) were used on almost as many acres of irrigated land as hand-moved systems (compare parts D and G in table 11). Value-wise CP's had become the leading type of sprinkler irrigation system, accounting for 43 percent of net capital values. By 1980 the CP shares had risen to 43 percent of all land sprinkler irrigated, and 54 percent of the net capital value in all sprinkler systems. Note, however, that sprinkler systems other than CP's, mobile--and also drop irrigation--are also becoming more important (see parts F and I in table 11).

Data were insufficient to complete a similar detailed analysis of different gravity irrigation methods. Definitions and coverage have varied from Census to Census and also among interested trade groups. According to the Census, flooding is still the most common gravity method. It accounts for about 44 percent of all land gravity-irrigated. Open ditches supply about 85 percent of the land flood-irrigated. The balance is flood irrigated from buried supply pipes.

Another 28 percent of the land gravity-irrigated is served with ditches and furrows, employing siphon tubes. About the same percentage is gravity irrigated with gated pipe.

Project Investment and Capital Growth

There are two broad types of irrigation projects: (A) Projects like the previously discussed Greeley, Anaheim and Riverside projects in Colorado and California. They were initially organized and undertaken without any governmental sponsorship or financing; and (B) projects planned, constructed and financed by the Federal Government, largely through the Bureau of Reclamation (USBR), even though operations and titles may have since been transferred to user organizations (29). In 1980 the two project types served 22.3 million acres or 41 percent of all irrigated land (table 3, figure 11).

In 1980 the type A projects served 12.2 million acres. This was most (55 percent) of the land requiring group water storage, diversion or conveyance facilities either on a full-supply, supplemental or temporary basis (table 3). The type B or USBR facilities served 10 million acres (45 percent) of all project lands.

Project Investment Rates

Table 5 compares gross and net average annual investment rates for project versus all onfarm irrigation improvements in the United States, averaged by the 16 five-year periods extending from 1901 to 1980. Figure 13 gives the gross and net real investment rates for project development. Disinvestment for non-USBR projects between 1920 and 1940 was more severe than figure 13 indicates, as the chart combines both USBR and non-USBR projects.

Between 1935 and 1975 net real investments in USBR projects were a fairly constant $200 million per year. For 1976-80 the rate averaged $122 million per year.

Net real investment rates for non-USBR projects recovered from negative Depression levels with the onset of World War II. They then steadily increased to a rate of $100 million per year between 1965 and 1970.

From 1970 to 1980, gross net investment in non-USBR projects averaged about $47 million per year. As depreciation averaged $59 million per year, real disinvestment in non-USBR projects again occurred in the 1970's, at a rate of -$12 million per year.

Project Capital Values

The division of gross and net irrigation capital into its project versus onfarm components since 1900 is shown in table 6. Trends in net capital values for project versus onfarm assets from 1900 to 1980 are graphed in figure 17. Since 1935 project capital has represented a generally decreasing share of all irrigation capital as well as of the total acreage needing project service. However, in 1980 project facilities still accounted for 53 percent of the gross stock of irrigation capital and 62 percent of its real net value (table 6, figure 17).

Federal Irrigation Investment

Under the Reclamation Act and other legislation the Federal Government has actively planned and constructed irrigation and multipurpose water resource development projects. About a fourth (24.9 percent) of real capital outlays for irrigation between 1870 and 1980 have been made by the Federal Government (table 2). The federally-financed (not the same as the federally-owned) share of irrigation capital assets declined significantly after 1975. In 1980 the Federal share was about 38 percent on a gross or original cost basis, but 46 percent on a net value basis (table 6). This difference is basically attributable to the near permanence of federally financed projects. The Federal share includes some cost-sharing for land preparation and similar improvements on farms as well as outlays for project construction (29, 30).

Nearly all Federal irrigation investment and construction has been through the Bureau of Reclamation (USBR) in the Department of the Interior and to a lesser but still important extent, through the Bureau of Indian Affairs in Interior. Table 7 is a recapitulation since 1902 of USBR construction investments, separating irrigation from other multipurpose water development activities (32). Since about 1965, USBR capital assets have been about equally divided between irrigation and nonirrigation purposes (table 7, figure 18).

USDA irrigation-related activities are primarily for technical assistance made available to farmers by the Soil Conservation Service, loan programs of the Farmers Home Administration. The Agricultural Conservation Program (ACP) and the Great Plains Conservation Program (GPCP) provide some cost-sharing for selected conservation improvements. In the case of irrigation such improvements are limited to leveling and similar land preparation activities. Water supply and equipment expenses must be borne entirely by irrigators.

The historical pattern of combined real Federal investment in irrigation by both USDA and the Department of the Interior is illustrated in figure 42. Corresponding investment data are in table 5.

Onfarm Investment and Capital Growth

Gross investments by individual farmers and ranchers in irrigation have surpassed project investment since 1940. Onfarm investment increased very sharply from 1976 to 1980 (table 5). Project investment continues of course, but has slackened somewhat and thus declined on a proportional basis. From 1976 to 1980, for example, the real gross new Federal irrigation investment was around $150 million per year (table 5). About $128 million of this (85 percent) went for project facilities and $22 million (15 percent) for helping reorganize existing farm systems to conserve water and reduce polluting effluents from irrigated land.

On the other hand, real gross investments by farmers for irrigation equipment and related improvements on irrigated farms averaged nearly $1.25 billion per year between 1976 and 1980. This was 88 percent of all new irrigation investment made in the United States from 1976 to 1980. Netwise, this translates to an annual increase of $560 million in the real net value of onfarm irrigation capital.

Investment Trends: Gravity versus Sprinkler Irrigation

This study distinguished only between gravity and sprinkler irrigation as two general irrigation methods. The Bureau of the Census also considers flood and drip or trickle irrigation as distinct methods. The problem in adhering to the Census convention is that only infrequently has the Bureau compiled national expenditure data corresponding to its defined irrigation methods. Therefore, this report treats flood irrigation as a form of gravity irrigation and drip irrigation as a form of sprinkler irrigation.

Annual real onfarm investments in gravity irrigation from 1900 to 1980 and sprinkler irrigation from 1940 through 1980 are recorded by 5-year periods in table 8. Figures 14 and 15 are separate charts for each method. They show that sprinkler investments have considerably outpaced new gravity irrigation investments on both a gross and net basis since about 1960. In the period 1976-80 sprinkler investment was almost 13 times as great as investment in gravity systems, while the additional acreage sprinkled during the period was about 9 times as great.

These comparisons reflect the fact that the capital requirements for installing sprinkler systems are generally much higher than for gravity systems. However, the latter usually involve higher labor requirements. This is a good example of how capital has been substituted for labor with respect to a particular production technique (irrigation) in agriculture.

Table 11 is a statistical and economic summary of how the technology of sprinkler irrigation has itself changed since 1940, focusing on gross and net investment rates and acreage additions for different system components, and types of distribution equipment.

Capital Stocks: Gravity and Sprinkler Irrigation

The aggregate capital committed to gravity and sprinkler irrigation on farms from 1900 to 1980 is also given in table 8, on both the gross stock and net value basis. Comparative net capital values are graphed in figure 19. Summary data for 1980 and the period 1976-80 also appear in table 2. Since 1972 the total value of sprinkler irrigation assets on farms has exceeded that for gravity irrigation. Per-acre averages are in table 10.

Investments by individual farmers and ranchers in irrigation have increased very dramatically since 1945 and are now far more important than public investment. From 1976 to 1980, for example, the real gross new Federal irrigation investment was about $150 million per year (tables 2 and 5). About $125 million of this went for project facilities and $25 million for helping reorganize existing farm systems.

Over the same period gross farmer investments for irrigation equipment and related improvements averaged $1.24 billion per year. This was almost 90 percent of all new irrigation investments made in the United States between 1976 and 1980. It translates to a $560 million annual increase in the net farm value of onfarm irrigation capital.

In 1980 sprinkler systems were used on about 35 percent of the land irrigated. However, they accounted for nearly 80 percent of the net capital value and about 75 percent of the gross stock of onfarm irrigation facilities and equipment. Recall that the 'gross stock' includes all the facilities and equipment now in use on farms, valued at their full cost in 1977 dollars. Net capital value is the present depreciated value in 1977 dollars of the same assets.

It appears that sprinkler irrigation capital grew at a much faster pace from 1976 to 1980 than did any other major component of farm business capital. Refer to tables 1 and 2. Real land values declined by 380 million (0.1 percent) per year. Farm service structures increased in value by $1.9 billion (3.6 percent) per year. Producers' durable equipment value rose by $2.1 billion (3 percent) per yer, while sprinkler irrigation net assets grew by $633 million (12.3 percent per year). These investments were divided about equally between water supply and water distribution systems.

From 1976-80 center-pivot (CP) irrigation systems accounted for a good two-thirds of all new net investment in sprinkler distribution systems. The CP net growth rate was $205 million or 18.6 percent per year, starting from a 1975 base of 50 percent of all sprinkler distribution capital. Second in line was drip irrigating, a more recent technology. Though not strictly 'sprinkler irrigation', its 1976-80 net growth rate was $47 million (14.5 percent) per year.

Irrigation Methods and System Size

Some added insights on the changing importance of different irrigation methods and their capital requirements can be obtained from the Census Bureau's follow-up 1979 Farm and Ranch Irrigation Survey, published in late 1982. About 259,000 farmers responded to the survey; they represented about 85 percent of the 303,000 farms that reported irrigating in 1978.

The special 1979 Census Survey permits some analysis of how different methods of irrigation depend on organizational factors like farm size. Survey data were not available when the sprinkler irrigation acreage and investment analysis in table 11 was completed. Inconsistencies are not significant, however. The 1979 Survey was thus a valuable supplement to this study of capital formation.

In the 1979 Survey, sprinkler methods were said to be used on 37 percent of all land irrigated but on nearly half (47 percent) of the irrigated farms. This implies that sprinkler systems do tend to be found on farms where relatively less land is irrigated and gravity systems on farms where irrigation is more extensive. However, the Survey data suggest also that at least 10 percent of the farmers irrigating in 1979 used both gravity and sprinkler systems.

About 7,000 farms reported using drip irrigation systems in 1979. About 321,000 acres were irrigated in this manner. The average per farm was rather high--45 acres. Fewer than a thousand farms (760) reported sub-irrigation, about 320 acres per farm. This per-farm average was higher than for any other irrigation method.

Gated pipe was used for 27 percent of the land gravity-irrigated but on only 15 percent of the farms with gravity irrigation. The area irrigated with gated

pipe averaged 215 acres per farm. For ditch and siphon tube installations the average was 184 acres per farm. The average for flooding systems was 166 acres per farm. States with significantly higher flood-irrigation acreages per farm included Florida (352), Arkansas (310), and Louisiana and Texas (both 212). The latter three States are leading rice producers. Others include Mississippi and California.

According to the Survey the amount of land irrigated with center-pivot systems (CP) in 1979 averaged 360 acres per farm. The CP average was significantly greater in eight States: Arizona (933), South Dakota (763), Idaho (681), California (615), Texas (510), Washington (448), and Kansas and Florida (both 397). The CP average for Nebraska was 287 acres per farm. Nebraska alone accounts for about a third of all land irrigated in the United States with center-pivot systems and for 40 percent of the farms having such systems.

About 175 acres was the average area of land irrigated on farms using mechanical-move sprinkler systems other than center pivots. For permanent and hand-moved systems per-farm averages were 60 and 55 acres, respectively.

The Survey findings reviewed here suggest definite correlations between type of farm, farm size and the kind of irrigation system likely used. These need to be investigated more thoroughly to gain a better understanding of how irrigation will further expand in different States and regions, with particular respect to changes in technology.

Past Investment as Capital and Wealth

Once made, irrigation investments become capital, like such other forms of physical capital as machinery and buildings. The investment required to prepare a given parcel of land for irrigation is a definite measure of an immediate increase in irrigation capital, as reflected in a minimum increase in the probable asking price of that land. If not fully maintained in its original condition the investment will tend to lose value (depreciate) over time so net capital value tends to decline.

At a particular point in time, net capital value represents current wealth from both a national and individual owner's point of view. In 1980, for example, the combined net capital value or real national wealth represented by all agricultural irrigation improvements and facilities was $23.7 billion in constant 1977 dollars. Around 9.1 billion (38 percent) of this was onfarm capital while 14.6 billion (62 percent) was project capital (table 2, figure 17).

Unit Capital Values

The combined net value works out to an over-all average of about $440 per acre on the 54 million acres irrigated in 1980. But 31.7 million acres were irrigated without any project service. It is best to speak of several averages, and also with regard to both net capital values and the gross capital stock as the operational value of assets in use. For example, in 1980 the value of project assets averaged $655 per acre served on a net capital value basis but $725 per acre on a gross basis (table 9). Onfarm irrigation assets averaged

$170 per acre net and $265 per acre gross (table 10). These averages are properly based on all land irrigated, including that provided project water.

Similarly, gravity irrigation system on farms were valued in 1980 at $55 per acre net and $95 per acre gross. Comparable average values for sprinkler systems were $375 per acre net and $575 per acre gross. For sprinkler systems these average values were split about 45:55 percent between water-supply and pumping requirements versus water distribution system (table 11).

Similar averages could be determined for the different types of sprinkler distribution equipment. In 1980 permanent sprinkler systems were used on 9 percent of all land sprinkler-irrigated but accounted for 18 percent of the net capital value of all sprinkler distribution equipment. Because of their comparatively high initial cost and long service life, however, permanent systems were valued at $340 per irrigated acre on a net basis and at $470 per irrigated acre on a gross basis (table 11).

Center-pivot systems in 1980 were used on 43 percent of all land sprinkler-irrigated. They accounted for more than half (54 percent) of the net value of all sprinkler systems. Net and gross center-pivot equipment values were respectively $215 and $350 per acre.

Additional Uses of Average Values

The per-acre irrigation capital values determined here have other potential uses. They may be used to construct current aggregate values for situations where the mix of existing irrigation service facilities and equipment may be known but historical investments are not known. A second use is in onfarm budgeting and enterprise analysis. For example, gross capital values per acre irrigated by a given method and using/not using project water can aid in estimating yearly capital consumption (depreciation).

Only in the case of dealing with a very new technology do the per-acre capital averages also represent irrigation development cost. However, examining the historical process of capital formation in irrigation produced information directly relevant to the problem of estimating marginal irrigation development cost for various technologies and water service conditions.

Marginal Irrigation Cost

Irrigation development cost can be regarded as the resources needed to install an irrigation system for a given tract of land or, more precisely, for an additional (marginal) acre of land if the question is how much land to irrigate.

Project development cost can be viewed in the same manner: It is the resources required to extend project service to a given additional acreage and added number of farms or, more precisely, to one more acre or farm. Guidelines for applying this concept of cost in irrigation projects and onfarm irrigation planning are covered in the literature. Some standard references include Carruthers and Clark, Golze', Huffman, Steele and Pavelis, and Withers and Vipond (25, 63-65, 67).

Marginal irrigation development costs (in constant 1977 dollars) for 1980 and years back to 1900 are given in table 9 for project irrigation and all onfarm systems regardless of irrigation method. The estimates apply to the United States as a whole. Marginal costs for gravity versus sprinkler irrigation on farms are in tables 10 and 11. Table footnotes explain how marginal costs (MC) were determined as statistical and econometric functions of acreage.

Differing MC functions for project, onfarm gravity and onfarm sprinkler irrigation are plotted in figure 20 on a comparable (dated) basis over the years 1900 to 1980, recognizing that MC is theoretically a function of acreage, not time. The 'theoretical' MC curves are in figures 22, 23 and 24.

Determining changes in the marginal cost of developing farm water supplies for irrigation and acquiring necessary irrigation equipment was also possible. Here the focus was on sprinkler irrigation. Dated MC functions for sprinkler water supply and pumping versus equipment needs are in figure 21. The theoretical curves showing MC versus acreage are in figure 22. The econometric procedures for deriving the component MC relations are explained under table 11.

Some special features of the marginal cost diagrams for project, gravity and sprinkler irrigation will conclude the irrigation discussion.

Project Marginal Cost

The MC associated with providing, if needed, an added acre of irrigated land with either a full or supplemental water supply from project storage diversion or conveyance facilities appears to have declined at a fairly constant rate since 1900. At that time 7.3 million acres were irrigated within projects. The project MC was $1,930 per added acre in 1900. By 1980 project MC had fallen to $1,220 per acre. About 22.3 million acres received project water in 1980. See table 9 and figures 20 and 22.

The project MC's combine full, supplemental and temporary water supply. This partly explains the fall in project MC over time, because Bureau of Reclamation projects have increasingly involved providing supplemental and temporary rather than total water requirements. A suggestion for future research is to adjust project MC's to a full-supply level, making them more comparable with the gravity and sprinkler MC functions.

Marginal Cost of Gravity Irrigation

The MC of initiating gravity irrigation U.S. farms in 1980 was about $615 for an added acre, moving from the 34.9 million acres then gravity-irrigated. Gravity irrigation MC in 1980 was thus 2.25 times what it was in 1945. Since 1945 it has increased at an average rate of close to $10 per acre per year. See table 10 and figures 20 and 23.

Marginal Cost of Sprinkler Irrigation

Marginal costs of sprinkler irrigation were determined from acreage and investment information covering the period 1940-1980. The average MC for all sprinkler systems was $900 per acre added in 1980, moving from the 19 million acres then sprinkler-irrigated. See tables 10 and 11 and figures 20, 21 and

24. The MC trend for sprinkler irrigation is quite different than those for project service and farm gravity systems. Sprinkler irrigation MC declined from $800 in 1940 to a minimum of about $585 per added acre in 1955, when about 2.25 million acres were sprinkler-irrigated. Since 1955 sprinkler MC has increased, to about $900 per added acre in 1980.

The sprinkler irrigation functions exhibit properties of classic marginal cost functions, first decreasing, then leveling off, and then increasing. Fortunately, from an analytical viewpoint it was possible to develop basic acreage and investment information for sprinkler irrigation over its significant technological life to date, essentially 1940 to 1980.

The component MC relations for sprinkler irrigation in figure 21 are particularly interesting. Water supply development MC has increased more rapidly than the MC of acquiring distribution equipment. This may reflect the need to drill deeper wells and purchase more costly pumping equipment. But it could also mean that more possibilities existed for improving water distribution systems than for improving drilling techniques and pumps.

While not shown graphically, marginal costs of different sprinkler distribution systems marketed since 1940 were also analyzed. The MC's for five general types of sprinkler systems used on a significant scale since 1940 are given in parts D through H of table 11 (see last column).

<u>Marginal Cost and Changing Irrigation Methods</u>

It was not a purpose of this study to investigate particular factors explaining the growth of irrigation but some likely candidates were: (1) World War II, which called for large increases in farm production, including in the arid West; (2) greater fertilizer use, the response to which is related closely to soil moisture; and (3) some severe humid-region droughts between 1955-65. These helped advertise and permanently establish irrigation as a normal production practice in new areas.

There have also been important changes in the technology of irrigation itself. Most of these were intended to simplify the practice, reduce per-unit energy and labor requirements, and otherwise make it possible to irrigate large areas quickly.

How do the marginal irrigation investment costs estimated in this study relate to these changes? In theory, the MC trends in figure 20 suggest that, having higher marginal investment cost, sprinkler irrigation would not have expanded as rapidly as gravity irrigation. The two methods are not pure practical or economic substitutes, however, even though cost-offsetting factors like lower labor requirements and its adaptability to a wider range of topographic conditions tend to favor sprinkler over gravity irrigation.

Marginal investment costs for sprinkler and gravity methods tended to 'converge' after 1955, with unit sprinkler costs falling as sprinkler irrigation got well underway (figure 20). By 1960 the gravity and sprinkler MC's were not greatly different. The acreage spriinkler irrigated has since increased much more rapidly than the acreage gravity irrigated.

There is the further element of 'irreversibility' regardless of comparative marginal cost. In 1970 real marginal cost of sprinkler irrigation was down to 115 percent of gravity irrigation investment cost but by 1980 had risen to 146 percent of gravity cost. Even so, between 1970-80 nearly 10 times as much land was newly irrigated with sprinkler systems as irrigated with gravity methods. On balance, one can conclude that comparative investment cost is a useful but probably not a key factor in explaining changes in irrigation methods on farms.

FARMLAND DRAINAGE

Drainage systems presently benefit about 15 percent of all non-Federal land used for crop or grazing purposes, and about 22 percent of all cropland. In terms of acreages improved farmland drainage is still the major component of land and water resource development in U.S. agriculture. It has a long history.

In 1787 Virginia and North Carolina chartered the Dismal Swamp Canal Company, formed for inland water transportation and land reclamation. Wooten and Jones indicate that George Washington and others had surveyed the area for these purposes in 1763. Maryland's drainage laws date back to 1790 and Delaware's to 1816 (53).

In the Swamp Land Acts of 1849 and 1850 the Federal Government granted to the States all swamp and overflowed lands in the public domain, on the condition that proceeds from their sale be used to reclaim such lands for agricultural and other purposes. Harrison describes how this Act, after a slow start, was a major stimulus to drainage development in the United States, especially in the Atlantic Coastal, lower Midwest and Mississippi Valley States (45, 46, 47). In the 1919 Yearbook of Agriculture, Hoswell recounts some practical and organizational difficulties experienced in such early drainage projects (48).

Information on drainage capital formation appears in tables 12 to 18 and figures 25 to 36. Some records going back to 1855 were usable for the study (38, 39, 42, 52). Long-term historical information given in the tables and charts is for every fifth year from 1900 to 1980. For example, table 12 and figure 25 give acreage drained with and without project facilities for decade and mid-decade years. Table 13 and figure 26 divide the aggregate acreage between surface and subsurface methods. Tables 14 and 15 (also figures 27 to 31) give average annual investment rates and the periodic status of capital values for project versus onfarm drainage systems.

Current Extent of Drainage

Van Schilfgaarde defines drainage as "the improvement of soil water conditions to enhance the agricultural use of the land. Such enhancement may come about by direct effects on crop growth, by improving the efficiency of farming operations or, under irrigated conditions, by maintaining or establishing a favorable salt regime." (41a, p.1).

Wesseling, Jones and others indicate that the dominant factors in how excess water inhibits crop growth are temperature and oxygen supply (41b, 49). Wet soils tend to be cold. Crop growth is slower and later than in drier soils. Also, oxygen is deficient in wet soils. This impedes root development,

microbiological activity, and the transport of nutrients through the plant. The restricted microbiological activity frequently leads to a nitrogen deficiency as well.

Extensive information on the hydrologic and physical principles involved in drainage, crop response, different ditch and tile designs, and on types of equipment installation and materials is provided in two American Society of Agronomy Monographs (No's. 7 and 17), especially in parts by Donnan, Schwab and Fouss, and van't Woudt and Hagan (40a, 40c, 41c, 41d). Drainage in conjunction with irrigation is discussed by Luthin, Donnan, Ochs and others (40b, 43, 44, 50).

Drainage Acreage Information, 1978 Census

According to the most recent drainage Census (1978), about 105 million acres of agricultural land in the United States benefited from artificial drainage (35). This total does not count normal provisions for proper drainage on irrigated land. It does count special drainage in irrigated areas necessary to alleviate and control soil salinity and temporary high water tables. About 10 percent of all land in farms, and about 23 percent of the Nation's cropland area of 471 million acres is presently drained (42a, 56).

Figure 2 shows the approximate current distribution of drained land across the United States. In the 1978 Census 17 States reported over a million acres of land drained for agricultural use. By millions of acres drained, these States were: Illinois (9.7), Iowa (7.7), Arkansas (7.0), Louisiana (6.9), Indiana (6.7), Florida (6.4), Minnesota (6.3), Mississippi (5.8), Texas (5.7), Michigan (5.5), North Carolina (5.3), Ohio (5.0), California (3.0), North Dakota (2.3), South Carolina (1.7), Maryland (1.2), and Tennessee (1.1). These 17 States contain about 85 percent of the farmland drained in the United States. Nearly three-fourths of all the farmland in Louisiana (72.4 percent) and over two-thirds of all the farmland in Delaware (67.2 percent) is drained. Eleven other States have from about 50 percent down to 20 percent of their farmland drained: Florida (48.5), Michigan (47.8), North Carolina (47.1), Arkansas (45.1), Maryland (44.3), Mississippi (41.6), Indiana (39.1), Illinois (32), Ohio (31), Iowa (23), and Minnesota (22).

Drained Area in 1980

For 1980 the area of farmland having improved drainage in the United States was determined in two ways and comes out to between 106.9 and 107.5 million acres. The closeness of the two figures does not necessarily imply great estimating precision. The lower figure is the national Census estimate for 1978 (105.3 million acres), plus about 1.6 million acres additionally drained in 1979 and 1980. The additions for 1979 and 1980 were assumed to be at least equal to the average acreage provided technical design assistance by the Soil Conservation Service between 1979 and 1981.

The higher figure for 1980 (107.5 million acres in table 12) was derived in six steps, independently of the 1978 Census. The starting point was the 44.5 million acres reported drained on farms in the 1930 Census of Agriculture. Specified increments and adjustments from various Census and other agency documents were then added or deducted (36, 37).

Long-Term Acreage Changes

Since about 1960 two kinds of adjustments appear to have characterized agricultural drainage: Less activity in organizing new projects in favor of independent farm systems, and a greater increase on subsurface than in surface system installations.

Project and Nonproject Drainage

Long-term acreages of farm drainage appear in table 12 and figure 25. An initial rapid developmental period for project drainage ended about 1920, by which time about 48 million acres had been brought within project service areas. This was over 97 percent of all land then drained.

There was a new surge of interest in project drainage just after World War II. It continued until about 1960. By then the share of land drained within projects (63 million acres) had fallen to 73 percent of all drainage. This was because independent farm drainage installations had expanded as well. For example, in the immediate postwar year 1946-50, over 60 percent of the nearly 4 million acres of land newly drained per year did not require project facilities. New drainage through the 1950's was again predominantly within projects, but since then new drainage has swung back toward independent farm installations.

Despite these changes it is important to recognize that most (63 percent) of the farmland drained in the United States in 1980 still relies on nonprofit public drains installed by townships, counties, special drainage districts and other organized entities. Some of these public drains and organizations are over 125 years old.

Surface and Subsurface Drainage on Farms

Of the 107+ million acres of farmland drained in the U.S. in 1980, about 84.7 million acres (80 percent) were drained with field ditches (table 13, figure 26). Another 22.7 million acres (20 percent) were drained with tile or other types of subsurface drains. Notable gains in subsurface relative to ditch systems since 1960 can be attributed to much improved methods and materials for tiling, although other technological advances, like laser beam grade-control devices, have made both methods of drainage and almost all land shaping operations in general more efficient (41c, 41d, 51).

Condition of Farm Drainage Systems

For many purposes information on the age and condition of drainage systems is more useful than the total area of drained land. In this work properly maintained public drainage channels and ditches were considered to have an indefinite service life (38).

The last two columns in table 13 give condition information on a continuous basis for farm drains since 1900, in terms of so-called 'undepreciated' drainage improvements. The term refers to farm surface systems (13.9 million acres in 1980) in place for less than 20 years (the assumed average useful life of ditch

systems), and to subsurface systems (13.8 million acres in 1980) in place for less than 40 years (their estimated useful life if installed since 1940).

One should not conclude, however, that surface systems more than 20 years old and subsurface systems more than 40 years old are no longer effective and of value to farmers.

Drainage Investment and Capital Growth

To briefly recap complete definition given earlier, drainage investment and capital includes: (a) Depreciable land improvements made to facilitate conveying excess water from fields either to simplify tillage operations or increase productivity, and either with surface ditching or with underground tile, plastic, mole and other drains; (b) durable equipment needed for drainage, such as pumps, power units, etc.; and (c) any other collection and durable disposal works like sumps, collection ditches, levees and other facilities, regardless of whether located and by whom financed and operated. This definition includes both group enterprise and farm drainage capital.

Project and Onfarm Capital Trends

Long-term investment and capital trends between 1900 to 1980 have tended to parallel but not be proportional to expansions in acreage. Many onfarm drainage systems are installed without any associated project facilities. The increasing importance of onfarm drainage improvements relative to project facilities shows up very strongly when investment costs are considered. In 1980, for example, the gross stock of drainage capital came to $12.7 billion, in 1977 dollars (tables 2, 15, and figure 30). Its net capital value was about $7.5 billion. In 1980 the gross stock was almost equally divided between project and onfarm assets (ratio 51:49 percent). The net capital values were weighted much more to project than to farm assets (ratio 60:40 percent).

Shorter service lives and resulting faster depreciation for farm drainage systems compared with project facilities partly explain the difference in these ratios. But different rates of new investment are also an important factor. For example, from 1976-80 the gross real investment for project drainage averaged $30 million per year (table 2). Depreciation was $55 million per year, giving a net disinvestment rate of -$25 million per year. Gross drainage investments on farms from 1976-80 averaged $145 million per year. Depreciation was $175 million per year, giving a net disinvestment rate of -$30 million per year. Thus, while disinvestment from 1976 to 1980 was about the same for project and onfarm drainage capital, new (gross) farm investment was nearly five times as much as new project investment.

Capital in Surface and Subsurface Farm Drainage

In 1980, the real investment cost per added acre of surface drainage was about $60 per acre compared with $370 for subsurface drains. The higher installation cost and longer useful life of subsurface drains mean that capital values for onfarm drainage activities are not in the same ratio as the areas drained with different methods.

In 1980, for example, subsurface drainage systems were used for 22.8 million acres. This was 21 percent of the land drained (table 13). But these subsurface systems had a gross stock value of $5.3 billion. This was 87 percent of the gross value of all onfarm drainage capital (table 16). The net capital value of subsurface systems was about $2.7 billion. This was close to 90 percent of the net value of all onfarm systems.

There have been declines in the gross real rate of new investment for farm drainage systems--since about 1950 for surface systems and since 1965 for subsurface systems (see table 16 and figures 28 and 29). Depreciation has been fairly constant.

Drainage Development Cost

Drainage development cost is the investment required to install or re-install a drainage system. This view is both practical and easily accomodated within economic theory. It is known definitely, being done 'today'. It measures the present economic value of the labor, materials, machine work, or other resources expended on drainage rather than some other use. Generally speaking, if the discounted future benefits less maintenance costs exceed installation cost, drainage is economically feasible and the required investment is warranted--for the particular rate of discount (interest) applied. Needless to say, the 'expected' benefits and costs as well as all immediate or future necessary investments need to be evaluated carefully, with suitable allowances for probable error.

Drainage investments become drainage capital, akin to other physical farm capital like irrigation systems, machinery, buildings and land. The investment required to drain a given parcel of land is a definite measure of an immediate minimum increase in drainage capital and probable asking price of that land. Of course, the investment will tend to lose value (depreciate) with time and/or use, so the current value of previous drainage improvements tends to decline. It will decline if gross new investment does not more than compensate for depreciation.

At a given time, net capital value constitutes current wealth, from either society's or the landowner's point of view. In 1980, for example, the combined net capital value, that is to say the national wealth, represented by all agricultural drainage improvements and facilities was $7.5 billion. Around $3.0 billion (40 percent) of this was in privately owned onfarm systems and $4.5 billion (60 percent) was in community or project works (table 2).

Marginal Drainage Cost

Marginal drainage cost (MC) is technically the value of the resources needed to install a drainage system for a given additional tract of land or, more precisely, an additional (marginal) acre of land if the question is how much land to drain. Marginal project service cost is the value of the resources required to extend project service to a given additional acreage and added number of farms or, more specifically, to one more acre or farm.

Estimates of marginal investment (MC) cost for 1980 and years back to 1900 are given in table 17 for project drainage, along with average MC for onfarm systems

regardless of drainage methods. MC's for surface versus subsurface farm drainage systems are in table 18. Table footnotes explain how MC's were determined as statistical functions of acreage. Figures 33-36 are corresponding cost diagrams.

Marginal Project Service Cost

The real investment cost of providing another acre of drained land with project outlets or other group facilities appears to have been quite stable since about 1915--at $145 per added acre (1977 dollars). See table 17 and figures 33-34. This estimate excludes any required associated onfarm cost. It was derived as the added gross investment by drainage organizations historically associated with a 1-acre net increase in the acreage drained within project service areas (39).

In the primary developmental stage for drainage, 1870 to 1920, marginal project costs per acre were higher. In 1900 project MC was $220 per added acre. Project MC's probably declined because of scale economies and, according to van Schilfgaarde, because of improvements in ditching machinery and a more thorough understanding of the physics of drainage (51).

A somewhat lower and statistically more 'reliable' project MC of $137 per added acre was obtained by confining the regression of cumulative real investment on net project service area to the years 1900-20 and 1945-80. In these two eras the aggregate U.S. project service area consistently expanded from year to year, though not at similar rates (table 12, figure 25). Gains in aggregate service area between 1920 and 1945 were not consistent each year.

Restricting the regression in this manner increased the coefficient of determination (R^2) to 0.94 from the 0.85 obtained by considering the entire 1900-80 period (table 17). But, recognizing that the respective MC's of $137 and $145 per added acre are almost the same and that new project development did occur during the years 1920-45, the results of the complete MC analysis are probably more reasonable. That is, $145 per added acre is a realistic estimate of the average real marginal cost (in 1977 dollars) of group drainage service in the United States.

Marginal Cost of Surface Drains on Farms

For surface drains on U.S. farms a revised analysis of marginal installation costs was restricted to the period 1915-80. 'Observed' costs as field estimates for relatively low acreages (before 1915) appear to represent a different statistical universe (isolated dots in figure 35).

The MC for surface drainage in 1980 was about $58 per added acre, reckoning from the nearly 85 million acres so drained. The computed MC for 1965 was $53 per added acre, reckoning from the 76 million acres having surface systems at that time. The real cost of installing ditch drains on farms thus appears to have risen very moderately if at all since 1965. It has been virtually constant in the last decade (table 18, figures 33, 35).

Marginal Cost of Subsurface Drains on Farms

The real marginal cost in 1980 of subsurface drainage on U.S. farms was estimated to be $370 per added acre (table 18, figures 33, 36). Nearly 22.8 million acres were then drained this way. While this MC was 20 percent more than in 1945, it was 10 percent less than in 1965. Declines in the real cost of installing subsurface drains can be attributed to the development of continuous plastic tubing, wider adherence to recommended standards for clay and concrete tile, and more efficient installation equipment (9c, 9d, 20).

Marginal Cost and Changing Drainage Methods

A declining MC for subsurface drains versus a moderately rising MC for surface systems was weighed against this factor: Land newly drained with subsurface relative to the land newly drained with surface systems has increased steadily since 1945. Subsurface systems accounted for 48 percent of the land newly drained between 1976 and 1980, compared with about 12 percent between 1946 and 1950. However, these proportions have fluctuated considerably over time. Only a weak correlation ($R=0.53$) was found in regressing the ratio of acreage additions for subsurface over surface drainage on the ratio of their respective marginal cost for the period 1946 to 1980.

An alternative approach involved regressing the total acreage having subsurface drains against the same ratio of respective marginal costs. Here the calculated correlation coefficient was -0.82 ($R^2=0.67$), the estimated correlation being 3.2 times its standard error. The 'true' correlation can be said to be at least -0.70, with no more than a 5-percent probability of it being less by chance. This statistical result suggests that the increasing importance of subsurface relative to surface drains is importantly though not entirely due to subsurface drainage 'tending' to become the more cost-efficient. How comparative real cost along with field conditions and other factors will influence future drainage methods is a promising area for interdisciplinary research.

Implications for Future Drainage

The analysis of marginal drainage costs does not presume that such cost relations will necessarily hold as more land is drained. However, several immediate uses are implied:

(1) Explaining why major changes in drainage organization and methods have occurred;

(2) Estimating the costs and investment requirements for relatively modest expansions in acreage and for different combinations of farm drainage systems and community outlets; and

(3) Analyzing the cost and the contribution of proper drainge to aggregate agricultural production capacity as well as a necessary element of land and water resource management on farms.

LAND AND ENVIRONMENTAL CONSERVATION

Natural resource conservation in the United States did not evolve in phase with the intensity of resource use. Rather, it came about in response to genuine and successful 'movements'. The pioneers in forest and parklands conservation were President Theodore Roosevelt, Ferdinand Hayden, Gifford Pinchot and John Muir. Forest reserves were established in 1891. In 1907 they were reorganized into the present system of National Forests managed by the U.S. Department of Agriculture. Yellowstone, the first National Park, was officially created in 1872 by President Grant.

The leading crusader for conservation on the Nation's farms was Hugh Hammond Bennett, though as Rasmussen says, the adverse effects of soil erosion were recognized early on by Thomas Jefferson, Edmund Ruffin and other influential leaders (54). Bennett's success in the 1930's was doubly significant because it involved drastic government intervention in the midst of the Great Depression and a time of widespread social distress along with minimal farm income. The emphasis on cost-sharing subsidies and income incentives in Federal conservation programs was a natural and understandable consequence of the adverse economic conditions prevailing when the programs were started.

Timmons has observed that in the 1970's four factors converged to cause new alarm over the condition of agricultural land: (A) An increased reliance on farm exports for improving the U.S. balance of payments and trade; (B) the fact that cash grains and oilseed crops are prime exports and also happen to be considered soil-depleting crops; (C) conversion of so-called fragile cropland and grasslands to cash crop production; and finally, (D) a reduced flow of new capital into conservation, with a possible serious decline in long-term productivity, and thus in the capacity for maintaining farm exports at high levels (55). Timmons discusses factors A and B in some detail. Statistics supporting factor C are in recent reports of Frey (56) and Daugherty (60). The focus in this study of natural resource capital formation was on factor D. Some productivity and policy implications of reduced conservation capital formation are quantified elsewhere (57).

The terrace and strip cropping dot maps in figure 3 indicate the approximate distribution of current conservation activities across the United States.

Aggregate Conservation Capital

From 1935 through 1980, cumulative conservation investments in the agricultural sector of the U.S. economy were $19.1 billion. When deflated to 1977 dollars, the total investment came to $43 billion (figure 39). The corresponding real gross capital stock in 1980 was $20.7 billion, which measured the real cost value of conservation improvements still in service. Slightly less than half of all conservation measures and improvements installed since 1935 should still be in place. Their net or partially depreciated capital value was $13.2 billion.

Compared with other farm business assets, the $13.2-billion net capital value of conservation improvements in 1980 amounted to 3.7 percent of the $356.7-million net value of all land in farms (table 1). Net land value means farm real estate value less all farm buildings. The value of conservation improvements in 1980 was about 22 percent as large as the capital value of all nonresidential

structures on farms, and 17 percent as large as the capital value of farm machinery and durable equipment.

In the peak year of 1955, conservation improvements came to 4.8 percent of net land value. They were nearly 60 percent as great as the value of nonresidential structures and almost 38 percent as great as the value of machinery and durable equipment on farms.

Onfarm Conservation Measures

Table 19 and figure 37 show average annual investments in onfarm conservation since 1935. From the beginning of a national conservation program in the mid-thirties through 1965, gross investments in onfarm conservation measures were very substantial, rivaling combined real investments for farm irrigation and drainage. In constant 1977 dollars, gross investments were $634 million per year from 1936 through 1940. They were nearly $1.5 billion per year during 1941-50. Between 1951 and 1965, gross investments dropped to an average of $900 million per year.

The rapid buildup of conservation capital meant growing depreciation allowances, so disinvestment, or negative net investment and a reduction in net capital values, began about 1957 (figures 37 and 40). The disinvestment rate fell to minus $351 million per year from 1971 to 1975. Disinvestment continued through 1980 though at a somewhat reduced rate, averaging minus $230 million per year between 1976 and 1980.

Substantial onfarm investments in soil conservation and rural environmental protection continue, but they are outweighed by depreciation allowances alone (58). Daugherty and Young report that about 5,000 landowners in the United States removed terraces, grass waterways, windbreaks, and strip-cropping systems during 1975-77 (59).

The net capital value of conservation measures on U.S. farms fell by about $230 million per year from 1976 to 1980. However, project conservation improvements gained in net value by about $75 million per year (compare figures 37 and 38).

The reason for such differences is not that gross project investments have exceeded those for onfarm measures. New projects during 1976-80 were only 40 percent as large as new onfarm investments. Rather, major structural improvements like those installed under the Flood Prevention Watershed Program in 1944 and the Watershed Protection and Flood Prevention Act of 1954 have longer service lives. Depreciation allowances deducted from gross new investment have been correspondingly less for project improvements, so net project investment tends to be closer to gross project investment.

From 1976 to 1980, for example, annual depreciation for existing conservation projects came to $102 million per year, or 60 percent of the gross investment rate of $176 million. Meantime, depreciation for onfarm conservation measures came to $677 million per year, about 1.5 times the gross investment rate of $447 million. Similar comparisons for earlier periods and for Federal conservation outlays may be made using the investment rates in table 19.

In real dollars, gross capital stocks and net capital values for onfarm conservation measures at first rose rapidly and then declined (table 20 and figure 40). Early on, the Government encouraged farmers to adopt quickly better tillage practices and conservation farming systems as a means of coping with severe soil erosion conditions, mostly in the South and Great Plains States.

As of 1980, about 52 percent of the gross stock and 46 percent of the net stock of conservation capital had been created from Federal cost-sharing and watershed programs. Despite fluctuations in Federal investment from year to year, the overall Federal share of conservation capital has changed little since cooperative conservation programs began in the thirties (table 20).

The rapid growth phase for U.S. farm conservation ended about 1955. By then, depreciation had begun to outweigh new investments, with a consequent decline in the net capital value of such improvements. In 1980, this value was $9.9 billion. The gross value of conservation improvements on farms peaked in 1965 at $27.6 billion. In 1980, gross value stood at $16.4 billion.

Conservation in Watershed Projects

Table 19 and figure 38 show average annual real investments in project conservation between 1945 and 1980. Watershed project investment encompasses the investments made since 1944 in the so-called 11 authorized Flood Prevention Watersheds, some of which are actually large river basins (27). Project conservation also includes investments in locally sponsored small watershed projects (under 250,000 acres) organized since 1954 under the Watershed Protection and Flood Prevention Act.

Although work in several of the flood prevention watersheds and in about 550 small watershed projects is now complete, cooperative watershed programs continue, but at a diminishing rate when considering inflation (21). Gross real investments for project conservation programs held fairly steady at about $200 million per year between 1960 and 1975 but fell to an average $176 million per year from 1976 to 1980. After allowing for depreciation, net investment in watershed project conservation averaged $74 million per year during 1976-80.

By 1980, project conservation facilities were valued at $4.3 billion on a gross-stock basis and at about $3.2 billion on a net value basis (table 19, figure 40). The net value was nearly 25 percent of the net capital value of all conservation improvements in agriculture. Most of the substantial gain for project conservation has occurred since 1960. Only 3 percent of the Nation's stock of conservation capital was then in project improvements.

Near-Term Outlook for Conservation

In December 1976, the Senate Committee on Agriculture and Forestry asked the Secretary of Agriculture to evaluate all USDA land and water conservation programs. Although eight different USDA agencies are officially involved in such programs, agencies that work directly with farmers and ranchers in action programs include ASCS, FmHA, ASCS, and the Forest Service. The evaluations centered on assessing the extent to which program and legislative objectives were being met; the program impacts on national conservation policies and

efficiencies in administration; and the validity of program purposes and mechanisms, considering present and projected conservation needs.

This evaluation effort was formalized in Public Law 95-192, the Soil and Water Resources Conservation Act of 1977 (RCA), which required the Secretary to develop a national soil and water conservation program for the Nation's private and other non-Federal lands.

The first formal RCA report was released in 1982 (61). The policies and program features approved by the Secretary address three major concerns: The reduction of soil erosion on all agricultural and forest land; water conservation in agriculture and reduction upstream flood damages; and State and local priorities, such as water-supply management, water-quality improvement, fish and wildlife habitat improvement, and organic waste management.

How redirected USDA programs will affect long-term conservation investments is not yet clear. USDA will likely emphasize matching funds, technical assistance, and research rather than direct Federal financial assistance to farm operators for installing conservation measures. The assistance will also tend to be concentrated (targeted) to critical areas and/or problems. Combined with reduced Federal spending in many budget areas, it is reasonable to expect that the Nation's aggregate stock of conservation capital, at least in the near term, will continue to decline. However, Department officials have reaffirmed that the control of soil erosion and flooding in agricultural watersheds should be USDA's first operational priority in protecting agriculture's natural resources (62).

EXTENDED USES AND RECOMMENDATIONS

Extended uses of this study of capital formation on the 'natural resource' side of agriculture mostly involve history, economic structure and methodology. As history and prologue the information can improve factual descriptions of American agriculture, expand our knowledge of the different modes of resource development in agriculture and the total economy, and improve anticipations of the level and composition of all depreciable capital relative to land, labor and other inputs.

With regard to economic structure, specific improvements in national economic accounts for the agricultural sector prepared periodically by the Department of Agriculture and other agencies have been proposed almost continuously in agricultural economics. In the 1970's Carlin and Handy pointed out that the family farm unit approach only partly determined the commitment and contribution of labor and capital to agricultural output and inevitably to the share of GNP originating in agriculture (68). Simunek observed that under present accounting rules certain outlays that represent investment are instead treated as current expense, and that fixed capital improvements to land, as for irrigation drainage and conservation, are not depreciated like other fixed assets (69). Penson and associates questioned the appropriateness of assumptions and techniques that underlie 'official' depreciation and capital stock estimates for machinery and similar fixed assets (70, 71).

By quantifying as well as recognizing natural resource capital and capital consumption both on and off farms, this study should significantly improve our knowledge of economic structure. The agricultural sector is modeled more realistically by identifying additional relevant forms of public and private investment, capital consumption and net investment. With natural resource capital acceptably defined, quantified, and included as a proper component of agricultural business capital, an objective basis is provided for assessing the marginal productivities and economic growth effects of continued investments in natural resources, whether made by the private or public sector.

In stressing methodology the study can guide similar regional or State surveys for the United States and other countries, especially where agricultural statistical services and national bookkeeping are still formative and thus fairly flexible. An interesting procedural lesson, attributed to the very close link between capital accumulation and technical change, is that state-of-the-art assessments and capital growth studies will be most successful if combined.

Another suggestion is to watch the technological horizon and monitor actual investments in successful innovations as soon as possible. Historically complete records of gross and net investment can then be used to develop fully 'rational' in preference to backwardly projected approximations of capital stocks.

APPENDIX A: NOTES AND REFERENCES

1. Various dates have been said to mark the closing of the frontier, and similar events that imply movement toward more intensive agriculture in the United States. In this study, 1900 was selected because only 16 of the 380 district land offices established since 1800 to dispose of the public land opened after 1900. Official closing dates are not relevant because of reorganizations and consolidations. All remaining comparable offices were abolished in 1970. After the Mineral Leasing Act of 1920, original land entries for agricultural purposes under all statutes fell from about 15 million acres per year to less than 4 million acres. The last surges in agricultural entries occurred in 1910 and just after World War I. Based on discussions with Julian Cox, Bureau of Land Management, U.S. Department of the Interior; and Philip Raup's chapter and other information in The Public Lands: Studies in the History of the Public Domain, (ed. V. Carstensen), Univ. of Wis. Press, 1963, pp. xii ff and 481 ff.

2. Fixed capital means physical assets that yield their productive services without undergoing any substantial changes in physical form. It does not mean that the assets stay fixed in place, unchanging in quality, or constant in value. Drainage ditches, buildings, and trucks are examples of fixed capital assets. Timber, coal, and feed stocks are examples of nonfixed assets.

3. Bajwa, Rajinder S., 1983, Humid Region Irrigation: Geographic and Economic Perspectives, Mich. Geog. Pub. No. 28, Univ. of Mich. (Ann Arbor).

4. Bajwa, Rajinder S., William M. Crosswhite, and Dwight M. Gadsby, 1983, Consumptive Use of Water and Supplemental Irrigation Needs for Selected Crops and Locations in the Southeastern United States. U.S. Dept. Agr., Econ. Res. Serv., Staff Report No. AGES830616.

5. Pavelis, George A., 1973, Energy, Natural Resources and Research in Agriculture: Effects on Economic Growth and Productivity for the United States. U.S. Dept. Agr., Econ. Res. Serv., presented at Joint Ann. Mtg., Am. Agr. Econ. Assn., Western Agr. Econ. Assn., and Canadian Agr. Econ. Soc., Edmonton, Alberta, Canada, August 1973.

6. Fisher, Irving, 1954, The Theory of Interest, Kelley and Milliman, Inc., New York.

7. Prest, A. R., and R. Turvey, 1965, "Cost-benefit Analysis: A Survey," Econ. Jour. 75(300):683-705. The connection of natural resource capital growth to income in a national or macro sense, while having theoretical validity, is imperfectly understood in empirical terms. Castle, Ciriacy-Wantrup, and Kelso detail some statistical and other reasons for this. See papers 2, 5, and 11 in Economics and Public Policy in Water Resource Development, (eds. Stephen C. Smith and Emery N. Castle), Iowa State Univ. Press, 1964.

8. Chryst, Walter E., and W. B. Back, 1966, "Perspectives on Content and Methodology of Land Economics," in Methods for Land Economics Research, (eds. W. L. Gibson, R. J. Hildreth, and Gene Wunderlich). Castle, Emery

N., 1965, "The Market Mechanism, Externalities, and Land Economics," J. Farm Econ., 47(3):542-66; Schultz, Theodore W., 1953, The Economic Organization of Agriculture, McGraw-Hill, New York; and Heady, Earl O., 1952, Economics of Agricultural Production and Resource Use, Prentice-Hall, New York.

9. An original discussion of investment and disinvestment in an environmental and general social setting is in Timmons, John F., 1954, "Economic Framework for Watershed Development," J. Farm Econ., 36(5):1170-83.

10. Medici argues that when labor or other goods are expended to improve primitive land a new indivisible property called land capital is created, and it is no longer possible to distinguish between land and added improvements. Medici, Guiseppi, 1953, Principles of Appraisal (translated from Principi di Estimo, Bologna, Italy), Iowa State College Press, pp. 187-88.

11. Gibson, James A., and John F. Timmons, 1976, "Information Needs and Models for Land Use Planning," Am. J. Agr. Econ. 58(5):903-8. For a popularized account of land-use transition issues from a public agency viewpoint see Land Use: Issues and Research Needs for Planning, Policy and Allocation, Coop. Task Force Report, Wash. State Univ., 1976.

12. This interpretation of fixed capital is from Kenneth Boulding's Economic Analysis, (revised) Harper and Brothers, 1948, pp. 262-70. In describing a division of capital into original goods and produced goods, Boulding calls land a prime example of an original good; namely, one that has not been produced by man. This agrees closely with the preceding Chryst and Back definition of land. But, Chryst and Back and Medici do not regard land in its natural form as being capital, whereas Irving Fisher, Friedman, and others do.

13. A Keynesian setting is convenient for examining the nature of investment. It describes the reasoning of entrepreneurs in deciding whether to increase their capital assets, and also extends the consequences of their decisions to invest or not to invest to the total economy. See, for example, Karl Fox, Intermediate Economic Statistics, John Wiley and Sons, 1965, Joseph P. McKenna, Aggregate Economic Analysis, The Dryden Press, 1972, and Alfred W. Stonier and Douglas C. Hague, A Textbook of Economic Theory, Longmans, Green and Co., Ltd., 1956. More fundamental treatments include John Maynard Keynes' The General Theory of Employment, Interest, and Money, Harcourt, Brace and Co., 1935; and P.N. Junankar's Investment: Theories and Evidence, MacMillan, 1972.

14. The usual way to demonstrate the quality of investment and saving is to first view an economy's total output and aggregate income for a given period (Y) as coming from the production and sale of either consumption goods and services (C) or from investment goods (I). The income of each receiver of income will either be spent on consumption of goods and services (again C) or not spent. Not spending is called saving (S). So, from the standpoint of the origin of income, Y = C + I. From the standpoint of how this income is allocated by recipients, Y = C + S. The

same total income is involved in either case, so C + I = C + S. Removing C from both sides of the identity gives I = S.

15. A comprehensive application of the perpetual inventory method is in the January 1974 report Fixed Nonresidential Business Capital in the United States, 1925-73. Bureau of Economic Analysis, U.S. Department of Commerce. See also Musgrave, John C., 1976, "Fixed Nonresidential Business and Residential Capital in the United States, 1925-75" in Survey of Current Business, 56(4):46-52. Another source which includes alternatives to the perpetual inventory method is Michael Ward's The Measurement of Capital: The Methodology of Capital Stock Estimates in OECD Countries, Organ. Econ. Coop. Develop., Paris, 1976.

16. Equations 3 to 10 are oversimplified in view of the present knowledge of capital theory. The aim is to describe a procedure that is technically correct and realistic, yet easily implemented, especially with respect to finding the required basic data. Jansma gives a reasoned and candid account of how perfecting detailed models, without recognizing the management and technical difficulties in obtaining the necessary empirical information, can impede research programs. See Jansma, J. Dean, Measuring the Impact of Natural Resource Investments on Employment, Income, and Economic Structure, Miss. State Univ., Southern Coop. Bull. No. 212, 1976.

17. Bureau of Reclamation officials advised the author that rehabilitation programs are usually undertaken only when annual maintenance expenditures become excessive. This means that rehabilitation would not account for the entire amount of depreciation in irrigation facilities. Part of the operation and maintenance costs could be regarded as depreciation, since lack of maintenance would result in the failure of irrigation systems over a period of years. Dredging distribution canals and laterals was given as an example.

18. Cumulative USBR construction appropriations were developed from annual (1903-80) Congressional appropriations for all USBR activities, less general allocations to operation and maintenance, loan programs, investigations, advance planning, administration, and emergency funds. These and additional annual data on construction fund allocations to irrigation and other USBR projects were supplied and explained to the author by Bureau staff in Washington, D.C.

19. Cumulative allocations of USBR construction funds to irrigation as a percentage of construction funding for all functions were used to divide the estimated actual cost of in-place project plant, property, and equipment between the irrigation and nonirrigation purposes of single and multipurpose projects. Actual costs (book values) for USBR facilities, by project and major project units, are updated annually in official reports of the Commissioner of Reclamation.

    This procedure presumes that facilities in place at a given time are related functionally to irrigation and other project purposes in line with original administrative allocations of construction appropriations. Deferral of project starts, construction delays, and similar lags were

assumed over the long-run to be offsetting in their effects on different USBR projects.

20. U.S. Dept. Agr., Agr. Stabil. Cons. Serv., (a) Agricultural Conservation Program: 45-year Statistical Summary, 1936-1980; (b) Agricultural Conservation Program: 1980 Fiscal Year Statistical Summary; (c) Practice Cost-Shares by States: 30-Year Summary 1944-74; and (d) National Practices and Guidelines, 1980.

21. U.S. Dept. Agr., Soil Cons. Serv., "Annual construction obligations for watershed protection projects (1957-80)," and "Annual obligations for flood prevention watersheds (1946-80)."

22. Gadsby, Dwight M., 1977, "Inventory of Benefits, Costs, and Other Data for P.L. 566 Watershed Work Plans Approved Through 1975," Econ. Res. Serv., U.S. Dept. Agr.

23. The USBR gross real investment in constant 1977 dollars represents the estimated cost of reproducing all existing irrigation and other project works at 1977 unit costs. The procedure for estimating real reproduction costs of USBR facilities is reviewed in some detail because it was helpful in estimating other irrigation, drainage and conservation assets.

    The real USBR investment was computed by first deflating yearly increases in current-dollar book values by appropriate construction cost indexes or deflators. After 1957, this was done separately for irrigation and other project purposes, and the results were added to obtain totals for all USBR facilities. The irrigation construction cost index for 1958-80 was taken as the simple average of USBR-derived subindexes for storage reservoirs, pumping plants, canals, conduits, laterals and drains, and associated buildings. The annual subindexes are from the report Construction Cost Trends, prepared by USBR's Engineering and Research Center in Denver.

    Before 1958 for irrigation, and since 1903 for all other purposes, construction costs were deflated to 1977 dollars by using the Engineering News Record (ENR) construction cost index (1900-24), the ENR index averaged with various other indexes for water structures (1925-46), or USBR's composite construction cost index (1947-80). The USBR composite index is updated in Construction Cost Trends, and periodically in the Survey of Current Business, along with other national income and product data published by the Bureau of Economic Analysis (BEA), U.S. Department of Commerce. Since 1947 BEA has used the USBR composite index for publicly funded water conservation and development structures.

24. The gross real investment in USBR irrigation facilities does not include a few early projects and parts of some abandoned projects written off with Congressional approval. These were considered to be the only element of capital retirement involved in USBR's irrigation program. Data in table 7 exclude such projects.

25. More information on depreciation and the estimated service life of numerous components of irrigation systems is in (a) Sprinkler Irrigation, (eds. Claude H. Pair, and others), Sprinkler Irrigation Association, Washington,

D.C.; (b) Sprinkler Irrigation, by Arthur F. Pillsbury and Ariosto Degan, Food and Agriculture Organization of the United Nations, 1968; (c) Design and Operation of Farm Irrigation Systems, (ed. Marvin Jensen), Mono. No. 3, Am. Soc. Agr. Engr., St. Joseph, Mich., 1980; and (d) Irrigation of Agricultural Lands, (ed. R. M. Hagan, H. R. Haise, and T. W. Edminster), Mono. No. 11, Am. Soc. Agr., Madison, Wis., 1967.

26. Because conservation farming systems and practices are so diverse and linked, no acreages corresponding to capital values were developed. One overall acreage indicator is the area in farms for which 'active' conservation plans have been developed with technical assistance from Soil Conservation Service. As of September 1980 the planned area was around 622 million acres and included about 2.3 million cooperative farms. The active plans covered about 60 percent of all land in farms.

27. The 11 Flood Prevention Watersheds include: Buffalo Creek, New York; Coosa River, Georgia and Tennessee; Little Sioux River, Iowa; Little Tallahatchie, Mississippi; Los Angeles River, California; Middle Colorado, Texas; Potomac River, Virginia, West Virginia, Maryland, and Pennsylvania; Santa Ynez, California; Trinity River, Texas; Washita River, Oklahoma and Texas; and the Yazoo River, Mississippi. See Eleven Authorized Flood Prevention Watersheds, 1970, U.S. Dept. Agr., Soil Cons. Svc., Bul. SCS-CI-15.

28. Pavelis, George A., 1978, Agriculture, Natural Resources, and Capital Growth: A Bibliography, U.S. Dept. Agr., Econ. Res. Serv., ERS Working Paper No. 45.

29. The net Federal investment in irrigation facilities is mostly (until about 1940 it was entirely) the net value of that portion of USBR investments in project property, plants, and equipment reasonably allocated to multipurpose or single-purpose irrigation projects.

30. Non-Federal irrigation investments include: (a) independent private investments in onfarm irrigation improvements and facilities from 1970 to 1975, including farm-owned irrigation equipment; (b) additional onfarm facility or land preparation investments made between 1936 and 1975 under the ACP or GPCP; (c) investments in group irrigation facilities made by irrigation organizations from 1870 to 1980, excluding facilities constructed and still owned by USBR; and (d) irrigation features of structures installed since 1954 under the Watershed Protection and Flood Prevention Act.

31. Acreage refers to the net area actually rather than possibly irrigated and corresponds with the Bureau of the Census item "irrigated land in farms". Certain totals are adjusted from Census or other reports to provide decade or mid-decade estimates and to fill in for missing years. USBR acreages are from various Bureau documents. The "other project" acreages and the "onfarm nonproject acreages" are compiled and adjusted from numerous Census and other sources.

32. From 1903 to 1949, net and gross capital values for USBR irrigation facilities are the same. After 1949, net values are less than gross

existing capital stocks by estimated cumulative expenditures for the rehabilitation of existing irrigation works. In this study USBR rehabilitation expenditures are considered to be analogous to depreciation allowances because they impose a demand on annual investment budgets but create no new capacity.

33. Irrigation project acreage (for service) refers to land for which irrigtion is feasible and intended, and for which project works have been constructed and water is available. The definition is from official USBR reports.

34. Net acreage irrigated refers to the irrigable project acreage actually irrigated in any year. The net acreage irrigated will include irrigated cropland harvested; irrigated pasture, cropland planted but not harvested; and the acreage in irrigation rotations used for soil-building crops. This definition is from USBR reports. It corresponds with the Bureau of the Census reporting item "irrigated land in farms."

35. The 1978 Census figures on artificial drainage are county and State estimates supplied by State and local SCS and other USDA offices. Farms were enumerated for drainage in the 1969 and 1974 Censuses, but results were not consistent and useful for comparisons, especially in 1974. Drainage on farms was reported fairly well in the 1920 and 1930 Census of Agriculture. From 1930 to 1969 only the 1940, 1950, and 1959 Censuses of Drainage Organization provide data on farm drainage. Estimates of net agricultural service areas were taken to approximate the amount of land actually drained on farms.

36. Lewis, Douglas, 1982, Land Drainage Investment Survey, 1975-77, U.S. Dept. Agr., Econ. Res. Serv. Staff Report No. AGES820525. This report does not distinguish between expenditures for newly drained land and those for replacement and repairs. New and existing sources of investment funds and technical assistance are not differentiated. But, many respondents said they did not use Federal planning assistance (58.6 percent), and did not benefit from Federal cost shares and loans (72.9 percent). This indicates that there may have been more new drainage activity in recent years than Census and other official reports indicate.

37. Details of the procedure follow (Data in millions of acres):

Begin:	Drained land on U.S. farms, 1930 Census of Agriculture:	44.524
Add:	Planted crops in 1940, within drainage organizations formed from 1931 to 1940 inclusive:	3.149
Less:	Area drained by irrigation districts, and drainage districts formed to solve irrigation seepage problems in 1940:	-2.236
Equals:	Estimated onfarm drained land in 1940 (no Census):	45.437
Add:	New SCS/ASCS drainage, 1941-80 inclusive:	62.046
Equals:	Estimated onfarm drained land for 1980:	107.483

38. Properly maintained project ditches and channels were considered to have an idefinite service life. To allow for reserves, however, one-half their original cost was depreciated over a 60-year period. After 60 years if not rebuilt, their net capital value is assumed to remain unchanged at 50 percent of their original real cost.

39. Construction and materials field costs for surface and subsurface onfarm drains were developed mostly from archival contract and material price lists, and interoffice field memos supplied by W. J. Ochs and R. Eugene Highfill of the Soil Conservation Service. Linus Losh, Ohio Department of Natural Resources; W. M. Gadsby, Dickens, Iowa; and Dwight M. Gadsby, Economic Research Service, USDA, also supplied some information. Project costs were developed from similar sources and from capital expenditures reported in the periodic Census of Drainage Organizations.

The marginal cost of $145 per added acre of project drainage is the first derivative of cumulative investment with respect to the acreage served as of every fifth year since 1900 (table 17). Successive differences in this acreage are the net result of interim decreases and increases. The incremental new investments are not exactly proportional to incremental increases in acreage. These were available until about 1940 by gross projejct areas rather than service area.

40. Amer. Soc. of Agron., 1957, Drainage of Agricultural Lands, (ed. James N. Luthin), Mono. No. 7, Madison, Wisc.; (a) Schwab, G. O., "Engineering for Land Drainage--General," pp. 287-315; (b) Luthin, James N., "Drainage of Irrigated Lands," pp. 344-71; and (c) van't Woudt, Bessel D. and Robert M. Hagan, "Crop Responses at Excessively High Soil Moisture Levels," pp. 514-78.

41. Amer. Soc. of Agron., 1974, Drainage for Agriculture (ed. Jan van Schilfgaarde), Mono. No. 17, Madison, Wisc., 700 pp.; (a) "Introduction," by van Schilfgaarde; (b) Wesseling, Jans, "Crop Growth and Wet Soils", (c) Donnan, W. W., and G. O. Schwab, "Current Drainage Methods in the USA;" and (d) Fouss, J. L., "Drain Tube Materials and Installation."

42. U.S. Dept. Commerce, Bureau of the Census, 1981, (a) "Drainage of Agricultural Lands," Vol. 5, pt. 5, 1978 Census of Agriculture, pp. vi ff; (b) selected Census reports on drainage for 1920, 1930, 1940, 1950, 1959, 1969, and 1974; and (c) the 1940 Census supplement by R. D. Marsden on Drainage of Alluvial Lands: A Comparison of Agriculture Within and Outside of Drainage Enterprises of the Lower Mississippi Valley, July 1943.

43. Donnan, William W., and George B. Bradshaw, 1955, "The Disposal of Seepage and Waste Water," In Water: 1955 Yearbook of Agriculture, U.S. Dept. Agr., pp.557-63.

44. Donnan, William W. and Clyde E. Houston, 1967, "Drainage Related to Irrigation Management," Irrigation of Agricultural Lands, Mono. No. 11, Am. Soc. Agron., Madison, Wisc.

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49. Jones, Lewis A., 1952, Farm Drainage, U.S. Dept. Agr., Farmers' Bul. 2046.

50. Ochs, W. J., L. S. Willardson, C. R. Ramp, Jr., W. W. Donnan, R. J. Winger, and W. R. Johnston, 1980, "Drainage Requirements and Systems," Design and Operation of Farm Irrigation Systems (ed. M. E. Jensen). Mono. No. 3, Am. Soc. Agr. Engr., St. Joseph, Mich.

51. Schilfgaarde, Jan van, 1971, "Drainage Yesterday, Today, and Tomorrow," Proc. Nat. Drainage Symp., Amer. Soc. Agr. Engr., Chicago, Ill., Dec. 6-7, 1971.

52. Weaver, M. M., 1964, History of Tile Drainage in America Prior to 1900, Waterloo, N. Y.

53. Wooten, Hugh H. and Lewis A. Jones, 1955, "The History of Our Drainage Enterprises," Water: 1955 Yearbook of Agriculture, U.S. Dept. Agr.

54. The political and legislative evolution of agricultural conservation programs in the United States is discussed in Wayne D. Rasmussen's "History of Conservation, Institutions and Incentives," Soil Conservation Policies, Institutions, and Incentives (eds. H. G. Halcrow, et al), Soil Cons. Soc. Am., Ankeny, Iowa, 1982. Batie reviews how conservation has become institutionalized at a local level. More complete references are W. Robert Parks' Soil Conservation Districts in Action, Iowa State Univ. Press, 1952; and Soil Conservation in Perspective by R. Burnell Held and Marion Clawson, Johns Hopkins Press, 1965.

55. Timmons, John F., 1979, "Agriculture's Natural Resource Base: Demand and Supply Interactions, Problems, and Remedies," presented at the National Conference on Soil Conservation Policies, Washington, D. C., Nov. 15, 1979.

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57. Pavelis, George A., 1983, "Conservation Capital in the United States, 1935-1980," Jour. Soil and Water Cons., 38(6):455-58.

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61. U.S. Dept. of Agr., 1982, A National Program for Soil and Water Conservation: 1982 Program Report and Environmental Impact Statement, Washington, D.C.

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APPENDIX B: STATISTICAL SUMMARIES

All investment rates and capital values given in the tables are for prevailing prices or unit costs prevailing during 1977 except where noted otherwise. A standard price base permits investments for different kinds of improvements, equipment, or facilities made in different years to be expressed as a common and additive unit. Estimates for natural resource capital can be compared and merged with other data on stocks of capital, like those prepared by the Departments of Agriculture and Commerce and other organizations. They are also consistent with the official National Income and Product Accounts (NIPA) for the United States.

Determining Capital Values

The following paragraphs give an empirical explanation of the perpetual inventory method for determining capital values from historical investment rates. All column references are to table 2.

Column 1: Initial Record Year

This is the earliest year researched in developing investment and capital stock information. Annual or available period amounts up to 1980 are included in total investment to date. However, gross capital stocks and net capital values are limited to assets not already fully depreciated. Drainage could be taken back to the mid-1850's, irrigation back to about 1870, and conservation back to 1936.

Column 2: Gross Investment to Date, Historical Dollars

Sum to date (1980) of gross investment by years or periods, from the initial record year. These raw totals are not adjusted for price-level changes. Annual investments on this basis are analogous to gross private and public domestic investment in current (historical) dollars continuously published in the official National Income and Product Accounts (NIPA) of the United States.

Column 3: Gross Investment to Date, Constant 1977 Dollars

Sum to date (1980) of gross investment after the yearly historical rates are indexed to 1977 costs and prices. Annual investments on this basis are analogous to gross private and public domestic investment, to be changed from constant 1972 to constant 1977 dollars in NIPA.

Column 4: Gross Capital Stock

The gross capital stock existing at the end of any year is the total investment to date, less those assets created earlier that have been abandoned or fully depreciated. The gross stock then represents those assets technically still in use. Such assets are valued at their full original cost, in constant 1977 dollars.

Column 5: Net Capital Value

From an economic accounting viewpoint, net capital value in real or constant 1977 dollars is derived as: (a) total investment to date in constant dollars (col. 3), less (b) all accrued depreciation allowances. Net capital value is both a measure of present real value and the depreciated book value of the gross capital stock. The difference between the gross capital stock and its net capital value is the amount by which those assets still in use have depreciated. Using 1980 as an example, and combining irrigation, drainage, and conservation, as shown in line 1 of table 2, these simple relations are set forth:

Billion dollars (1977)	U.S. totals as of 1980
109.525	Total investment to date, constant dollars (col. 3)
-65.130	Less: All depreciation to date
44.397	Equals: Net capital value in 1980 (col. 5)
Also:	
109.525	Total investment to date (col. 3)
-45.604	Less: Capital fully depreciated (and retired)
63.921	Equals: Gross capital stock in 1980 (col. 4)
-44.397	Less: Net capital value in 1980 (col. 5)
19.524	Equals: Accrued depreciation on assets still in use

Columns 6 and 7: Percentage Shares

These will vary in any year according to the past time-stream of current-dollar and constant-dollar investment for the different capital components, deflators appropriate to each component, specific useful lives, and depreciation methods.

Column 8: Gross Annual Investment

This includes all capital expenditures for new facilities and equipment or for major repairs and rehabilitation of existing facilities. Routine maintenance and operating costs are not customarily included in capital investment accounts. Additions to the gross capital stock will occur only in years when gross annual investment is greater than the full original cost of assets that have become fully depreciated and are now scheduled for retirement. The gross capital stock will decline if scheduled annual retirements exceed gross new investment.

Column 9: Annual Depreciation Allowances

These depend on the expected useful lives of assets still in use, particularly on methods for figuring depreciation and on the magnitude of past investments. The latter are reflected in the size of gross stocks and net capital values. For project-type facilities having an indefinite service life, like those constructed by USBR, a proxy for depreciation was the outlay for major repair, replacement, and rehabilitation of existing works. Otherwise, straight-line depreciation methods were employed. This means that depreciation was computed against the gross capital stocks and allocated equally over the expected

service life of the different facilities and equipment. Table 21 summarizes service lives used in calculating depreciation allowances.

Column 10: Net Annual Investment

Net annual investment is gross annual investment (col. 8) less the annual depreciation allowance (col. 9). Net investment is thereby the annual change in net capital value. Net annual investments added up since the first year of record will be the net capital value as of the end of any given year. In years when gross annual investment exceeds depreciation allowances, net annual investment will be positive. Net capital value will increase by the amount of the net investment. Similarly, disinvestment (declines in net capital) will occur if gross annual investment does not cover depreciation allowances. Net investment will then be negative and net capital value will decline by the amount of the deficiency.

Other Financial Features

Decade and Mid-decade Figures

Acreages, capital stocks and related data are generally recorded in the tables by quinquennial or 5-year intervals, beginning with 1900 and ending with 1980. However, drainage investments since 1855 and irrigation investments since 1870 were analyzed. Information available only for certain years, not necessarily coinciding with the end or middle of decades, like Census material collected at regular but different intervals, was synthesized annually by noting trends in a discrete or partial series and interpolated for the missing years. The synthetic annual series was then collapsed to show only end-of-decade and mid-decade figures. This procedure was essential for deriving consistent capital stock and investment data on non-Federal project irrigation facilitites, all project drainage works, and farmer-owned irrigation equipment.

Units of Measure

Great precision is neither possible nor essential in analyzing capital growth in a broad economic sector like American agriculture. Estimates of net and gross value are given in billions of dollars rounded to the nearest million dollars. The more detailed estimates are either in millions or billions of dollars, rounded to the nearest $5 million. Most aggregate acreages are shown in millions rounded to the nearest 5 thousand acres, but acreage change rates are to the nearest 1,000 acres. While an effort was made to choose and round units so that totals could be the exact sum of their respective parts, some minor rounding discrepancies may remain.

Sources, Sequence, and Arrangement

Leading sources of information are cited under the table considered most general to a subject. Other sources are given in appendix A, especially where questions of choice, availability, and the simultaneous use of various materials were involved in developing acceptable acreage, investment, and capital stock estimates. Actually, about 400 references were consulted while planning and conducting the study. Most are catalogued in another publication (28).

To facilitate comparisons within and among topics the statistical information is arranged in the same format where possible. Table 1 is viewed best as a compositional recapitulation since 1900 of all capital stocks in agriculture. It shows how different forms of capital are interrelated, how estimates on particular categories can sometimes be derived by removing unwanted items from known aggregates, and how newly identified categories can themselves be used to form meaningful new aggregates.

Table 2 summarizes the derivation and composition of irrigation, drainage, and conservation capital as of 1980. It also shows source-of-fund distributions between the Federal and other sectors, project versus onfarm capital, and capital stocks associated with various irrigation and drainage methods. Average annual gross and net investment rates from 1976-80 are also included.

Beginning with table 3, the various natural resource acreage and capital stock data are tabulated by 5-year intervals since 1900. Many are then divided into Federal and non-Federal components as the principal identifiable modes of development and financing. This highlights the role of public finance in this aspect of American economic development, especially for irrigation and conservation. Another breakdown is by type and location of facilities, for example, onfarm and project improvements. A third general breakdown identifies methods for onfarm irrigation, for example, gravity and sprinkler irrigation systems, and surface and nonsurface drainage systems on farms.

Table 1--Components of total and fixed real stocks of land and other physical capital in U. S. agriculture, 1900-80

Year	All land and other physical capital	Less: Net value of farm homes	Equals: Farm business capital	Less: Livestock and crop inventories	Equals: Land and fixed business capital	Less: Net value of land alone	Equals: Depreciable business capital	Depreciable business capital (by types): Farm service structures	Producers' durable equipment	Natural resource capital	Resource capital (by types) 1/: Onfarm resource capital	Resource project capital
	--Billion dollars (1977)--											
1900	362.5	17.7	344.8	24.7	320.1	304.6	15.5	8.4	5.4	1.7	.3	1.4
1905	383.4	31.0	352.4	35.4	327.0	300.9	26.1	14.9	7.7	3.5	.5	3.0
1910	407.2	40.0	367.2	26.0	341.2	303.8	37.4	19.7	10.8	6.9	.7	6.2
1915	422.4	49.1	373.3	27.6	345.7	298.6	47.1	23.6	13.8	9.7	1.0	8.7
1920	439.9	59.2	380.7	29.5	351.2	293.4	57.8	28.6	17.4	11.8	1.2	10.6
1925	449.3	57.2	392.1	29.9	362.2	309.2	53.0	27.5	13.5	12.0	1.3	10.7
1930	460.7	55.7	405.0	29.5	375.5	321.3	54.2	25.3	16.7	12.2	1.3	10.9
1935	446.7	50.9	395.8	30.9	364.9	321.5	43.4	20.0	12.2	11.2	.9	10.3
1940	456.2	48.5	407.7	33.7	374.0	326.5	47.5	17.0	15.9	14.6	4.2	10.4
1945	465.0	46.1	418.9	37.9	381.0	323.6	57.4	15.3	19.7	22.4	11.5	10.9
1950	515.9	49.2	466.7	37.7	429.0	335.5	93.5	23.1	38.4	32.0	20.1	11.9
1955	541.7	47.7	494.0	42.9	451.1	343.4	107.7	28.3	43.4	36.0	22.6	13.4
1960	547.7	44.9	502.8	44.4	458.4	347.4	111.0	32.1	41.3	37.6	22.6	15.0
1965	560.6	42.7	517.9	49.2	468.7	346.9	121.8	36.9	45.2	39.7	22.1	17.6
1970	577.2	40.7	536.5	51.3	485.2	347.6	137.6	42.3	54.0	41.3	21.4	19.9
1975	613.5	39.3	574.2	57.9	516.3	358.8	157.7	49.5	65.9	42.1	20.5	21.5
1980	641.6	38.5	603.1	66.6	536.5	356.9	179.6	59.0	76.3	44.3	22.0	22.3
Percentage shares in 1900, 1920, 1940, 1960, and 1980 (bracketed columns add to 100 percent of net capital value for item to left)												
1900	100	5	95	7	93	95	5	54	35	11	20	80
1920	100	14	86	8	92	83	17	50	30	20	11	89
1940	100	11	89	8	92	87	13	35	34	31	29	71
1960	100	8	92	9	91	76	24	29	37	34	60	40
1980	100	6	94	11	89	67	33	32	43	25	50	50

SOURCES: For natural resource capital see tables 6, 11, 15, and 20. For other types of farm capital see:

Alvin S. Tostlebe, The Growth of Physical Capital in Agriculture, 1870-1950, Nat. Bur. Econ. Res., Occas. Pap. 44, 1954; also Tostlebe's Capital in Agriculture: Its Formation and Financing since 1870, Princeton Univ. Press, 1957; and John C. Musgrave, "Fixed capital stock in the United States: Revised estimates, 1925-79," Surv. Curr. Bus. 61(2):57-68, Feb. 1981.

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1/ Net capital values as of 1980 for irrigation, drainage, and conservation components of natural resource capital are in table 2 (col. 5).

Table 2--Irrigation, drainage, and conservation capital in U.S. agriculture: Percentage as of 1980 and average annual investment, 1976-80 1/

Capital components 2/	(1) Initial record year	(2) Gross investment to 1980: Historical dollars	(3) Gross investment to 1980: Constant dollars	(4) Capital stocks in 1980: Gross capital stock	(5) Capital stocks in 1980: Net capital value	(6) Percentage shares as of 1980: Investment to date	(7) Percentage shares as of 1980: Net capital value	(8) Average annual investment, 1976-80: Gross investment	(9) Average annual investment, 1976-80: Annual depreciation allowance	(10) Average annual investment, 1976-80: Net investment 4/
		Billion dollars	----Billion dollars (1977)----			---Percent 3/ ---		----Million dollars (1977)---		
All natural resource capital	1855	43.810	109.525	63.921	44.397	100.0	100.0	2,207	1,748	459
Irrigation Capital	1870	19.043	48.163	30.535	23.707	43.9	53.4	1,409	739	670
Drainage Capital	1855	5.619	18.361	12.664	7.520	16.7	16.9	175	230	-55
Conservation Capital	1936	19.148	43.001	20.722	13.170	39.4	29.7	623	779	-156
Irrigation capital	1870	19.043	48.163	30.535	23.707	100.0	100.0	1,409	739	670
Farmer/nonfederal share	1870	14.257	36.173	18.997	12.720	75.1	53.7	1,260	700	560
Federal investment	1902	4.786	11.990	11.538	10.987	24.9	46.3	149	39	110
Project facilities	1870	6.922	25.244	16.192	14.629	52.4	61.7	169	59	110
a. Bureau of Reclamation	1902	4.235	10.894	10.894	10.720	43.2	73.3	127	5	122
b. Other projects	1870	2.687	14.350	5.298	3.909	56.8	26.7	42	54	-12
Onfarm facilities	1870	12.121	22.919	14.343	9.078	47.6	38.3	1,240	680	560
a. Gravity irrigation	1870	3.055	8.621	3.349	1.906	37.6	21.0	91	164	-73
b. Sprinkler irrigation	1940	9.066	14.298	10.994	7.172	62.4	79.0	1,149	516	633
Drainage capital	1855	5.619	18.361	12.664	7.520	100.0	100.0	175	230	-55
Farmer/nonfederal share	1855	5.188	17.383	11.877	7.213	94.7	95.9	165	203	-38
Federal investment	1941	0.431	0.978	0.787	0.307	5.3	4.1	10	27	-17
Project facilities	1855	1.510	9.255	6.505	4.486	50.4	59.7	30	55	-25
Onfarm facilities	1855	4.109	9.106	6.159	3.034	49.6	40.3	145	175	-30
a. Surface drainage	1855	1.117	2.893	0.813	0.341	31.8	11.2	22	47	-25
b. Subsurface drainage	1855	2.992	6.213	5.346	2.693	68.2	88.8	123	128	-5
Conservation capital	1936	19.148	43.001	20.722	13.170	100.0	100.0	623	779	-156
Farmer/nonfederal share	1936	9.854	21.628	9.775	7.084	50.3	53.8	333	344	-11
Federal investment	1936	9.274	21.373	10.947	6.086	49.7	46.2	290	435	-145
Conservation projects	1944	2.735	4.332	4.332	3.234	10.1	24.6	176	102	74
Onfarm measures	1936	16.413	38.669	16.390	9.936	89.9	75.4	447	677	-230

1/ Columns are explained in appendix B. 2/ Numbered items are alternative breakdowns of the same totals for irrigation, drainage, and conservation. Shares refer to original sources of funds, not necessarily to current ownership. 3/ Percentages are of immediate totals in 1977 dollars, and grouped percentages for lettered subitems add to 100. 4/ Net investment per year = gross investment per year less depreciation allowance per year.

Table 3 -- Total irrigable land and net acreage irrigated with and without project facilities, United States, 1900-80

Year	Total irrigable acreage 1/	Net acreage irrigated 2/	Type of water service facilities: Bureau of Reclamation projects 3/	Type of water service facilities: Other irrigation projects 4/	Type of water service facilities: Total project irrigation	Type of water service facilities: Irrigated without projects	Acreage shares: Project service share	Acreage shares: Share without projects
			--Million acres--				--Percent--	
1900	12.080	7.700	--	7.300	7.300	0.400	94.8	5.2
1905	12.320	8.640	.020	8.140	8.160	.480	94.4	5.6
1910	14.037	10.000	.473	8.980	9.453	.547	94.5	5.5
1915	15.441	11.195	.857	9.555	10.412	.783	93.0	7.0
1920	17.640	13.350	2.205	10.135	12.340	1.010	92.4	7.6
1925	18.099	13.815	2.339	10.235	12.574	1.241	91.0	9.0
1930	18.753	14.600	2.791	10.340	13.131	1.469	89.9	10.1
1935	16.333	13.000	2.936	8.845	11.791	1.219	90.6	9.4
1940	21.681	18.120	3.391	9.902	13.293	4.827	73.4	26.6
1945	24.413	20.665	4.163	11.085	15.247	5.418	73.8	26.2
1950	29.227	25.905	5.077	9.900	14.977	10.928	57.8	42.2
1955	33.771	30.275	6.262	10.860	17.122	13.153	56.6	43.4
1960	37.406	33.940	6.900	10.980	17.880	16.060	52.7	47.3
1965	41.350	37.470	8.012	11.410	19.422	18.048	51.8	48.2
1970	45.593	41.630	8.570	12.295	20.865	20.765	50.1	49.9
1975	50.251	46.250	9.309	12.270	21.579	24.671	46.7	53.3
1980	59.444	54.014	10.092	12.245	22.337	31.677	41.4	58.6

SOURCES: See table 6.

1/ Total irrigable acreage (for service) refers to lands for which irrigation is feasible and itended, and for which project works or onfarm facilities are in place and the required water is expected to be available. This definition is followed in official Bureau of Reclamation project reports.

2/ Net acreage irrigated includes irrigated cropland harvested, irrigated pasture, some irrigated crops planted but not harvested, and the acreage in irrigation rotations used for soil-building crops. This definition is used by the Bureau of Reclamation and is also consistent with the census reporting item irrigated land in farms. In the case of irrigation projects, net irrigation is that part of the irrigable project acreage actually irrigated in a particular year. The required water can be provided in whole, in part, or temporarily from project storage and diversion facilities.

3/ Includes all projects constructed by the Bureau of Reclamation, although most projects are now operated by other irrigation organizations and agencies, such as irrigation districts, mutual companies the Bureau of Indian Affairs, commercial companies, and State and local governments.

4/ Remaining area serviced by projects and organizations not using facilities constructed by the Bureau of Reclamation.

Table 4 -- Net acreage irrigated by gravity and sprinkler systems, with average annual changes in acreage, United States, 1900-80

Year	Net irrigated acreage 1/	Gravity irrigation systems 2/	Sprinkler irrigation systems 3/	Acreage shares: Gravity irrigation	Acreage shares: Sprinkler irrigation	Average annual change, past 5 years: All irrigation	Average annual change, past 5 years: Gravity irrigation	Average annual change, past 5 years: Sprinkler irrigation
	Million acres			Percent		Thousand acres		
1900	7.700	7.700	--	100.0	--	--	--	--
1905	8.640	8.640	--	100.0	--	188	188	--
1910	10.000	10.000	--	100.0	--	272	272	--
1915	11.195	11.195	--	100.0	--	239	239	--
1920	13.350	13.350	--	100.0	--	431	431	--
1925	13.815	13.815	--	100.0	--	93	93	--
1930	14.600	14.600	--	100.0	--	157	157	--
1935	13.000	13.000	--	100.0	--	-320	-320	--
1940	18.120	17.850	4/ .270	98.5	1.5	970	970	4/ 14
1945	20.665	20.250	.415	98.0	2.0	509	480	29
1950	25.905	24.915	.990	96.2	3.8	1,048	933	115
1955	30.275	28.005	2.270	92.5	7.5	874	618	256
1960	33.940	30.500	3.440	89.9	10.1	733	499	234
1965	37.470	31.940	5.530	85.2	14.8	706	288	418
1970	41.630	33.805	7.825	81.2	18.8	832	373	459
1975	46.250	34.150	12.100	73.8	26.2	924	69	855
1980	54.014	34.950	19.064	64.7	35.3	1,553	160	1,393

1/ Net irrigated acreage is defined in table 3.

2/ Gravity irrigation may involve: (a) open or covered canals or conduits, from which water is brought to fields in supply ditches and then directly turned or siphoned into furrows; (b) underground or above-ground piping from water sources, with turnout valves for each major point of field supply; or (c) underground or above-ground piping directly from water sources to the plants, as in nurseries and orchards. In sprinkler irrigation, water distribution is by gravity flow. The water may first be pumped from wells, reservoirs, and streams, may come from free-flowing springs and wells, or may simply be diverted from streams and reservoirs at points higher than the area to be irrigated.

3/ In sprinkler irrigation, water is discharged under pressure through perforated pipe, stationary sprinklers, rotating sprinklers, and various types of nozzles. Sprinkler systems are generally regarded as permanent, semiportable, or portable with respect to whether and how the distribution equipment is moved, not necessarily the pump or water supply source.

4/ The 270 thousand acres of sprinkler irrigation in 1940 is assumed to have begun in about 1920, with the permanent systems installed in some orchards, vineyards, and nurseries. This implies an average annual increase in sprinkler irrigation of about 14 thousand acres until 1940.

Table 5 -- Average annual gross and net real capital investment in project onfarm irrigation, and with Federal investment, United States, by 5-year periods, 1901-80

Period	Gross annual irrigation investment 1/: All investment	Project facilities 3/	Onfarm facilities 4/	Federal investment 5/	Net annual irrigation investment 2/: All investment	Project facilities	Onfarm facilities	Federal investment
	Million dollars 1977							
1901-05	290	272	18	25	220	215	5	25
1906-10	520	485	35	81	410	390	20	81
1911-15	507	470	37	128	339	322	17	128
1916-20	502	422	80	47	280	224	56	47
1921-25	147	126	21	40	-70	-86	16	40
1926-30	149	111	38	34	-114	-113	-1	34
1931-35	190	154	36	65	-114	-70	-44	65
1936-40	340	264	76	163	105	73	32	163
1941-45	494	297	197	150	287	144	143	148
1946-50	737	337	400	232	555	231	324	222
1951-55	664	311	353	258	465	271	194	239
1956-60	657	307	350	268	363	263	100	247
1961-65	808	414	394	313	407	358	49	272
1966-70	923	364	559	254	390	292	98	208
1971-75	952	264	688	238	408	203	205	189
1976-80	1,409	169	1,240	148	670	110	560	109

1/ Gross real investment in irrigation is one-fifth the sum for the period of annual irrigation investments in current dollars, after each yearly amount was indexed (deflated) to 1977 price levels. Information developed by 5-year intervals if annual data not available.

2/ Net real investment is gross real investment less depreciation allowances on existing gross capital stocks. Average depreciation for each component and period can be determined by subtracting (algebraically) net investment rates from corresponding gross rates. For example:
All depreciation, 1931-35: 190-(-114) = 190 + 114 = $304 million/year (in 1977 dollars).
All depreciation, 1976-80: 1,409-670 = $739 million/year (in 1977 dollars).

3/ Includes capital investments in project-type facilities by any irrigation organization that supplies irrigation water to two or more farms or ranches. Organizations can be private or commercial companies, mutual or cooperative groups of landowners, irrigation districts established under State law, State agencies, and municipal systems if they supply irrigation water to more than 100 areas. Also includes irrigation capital expenditures by such Federal agencies as the Bureau of Reclamation and the Bureau of Indian Affairs in the Department of the Interior.

4/ Covers investments in all onfarm irrigation improvements and durable equipment, such as land preparation; ditches, wells and other water supply improvements; and pumps, power units, sprinkler system, pipes, and other nonexpendable supplies.

5/ Direct Federal capital investment for irrigation was minor before the Reclamation Act of 1902. From then until 1943, Federal investment includes only irrigation project works planned and installed under the Reclamation Act and related authorities. Since 1944, Federal investment also covers cost-sharing assistance for irrigation improvements made under USDA's Agricultural Conservation Program. Since 1959, it also accounts for similar assistance authorized under the USDA's Great Plains Conservation Program.

Table 6 -- Real gross capital stocks and net capital values for project onfarm irrigation facilities and systems, with Federally financed shares, United States, 1900- 80

Year	Gross capital stock, irrigation facilities 1/				Net capital value, irrigation facilities 2/			
	All irrigation	Project facilities 3/	Onfarm facilities 4/	Federal share 5/	All irrigation	Project facilities	Onfarm facilities	Federal share
	Billions dollars (1977)	--------- Percent 6/	--------		Billions dollars (1977)	--------- Percent 6/	---------	
1900	1.248	75.3	24.7	--	0.709	69.5	30.5	--
1905	2.462	83.9	16.1	5.1	1.808	86.7	13.3	6.9
1910	4.749	89.2	10.8	11.2	3.856	91.2	8.8	13.8
1915	6.973	91.3	8.7	16.8	5.553	92.3	7.7	21.2
1920	9.168	89.9	10.1	15.4	6.952	89.8	10.2	20.3
1925	9.827	90.3	9.7	16.4	6.600	88.1	11.9	24.5
1930	10.482	89.9	10.1	17.0	6.028	87.0	13.0	29.6
1935	9.832	91.1	8.9	21.5	5.459	89.7	10.3	38.7
1940	9.517	86.8	13.2	30.8	5.986	88.0	12.0	48.9
1945	9.705	82.9	17.1	37.9	7.422	80.7	19.8	49.6
1950	11.232	70.0	30.0	42.9	10.199	70.0	30.0	46.9
1955	14.353	65.6	34.4	42.4	12.523	67.9	32.1	47.6
1960	17.098	64.0	36.0	43.1	14.336	68.5	31.5	50.0
1965	20.929	62.2	37.8	42.2	16.370	70.9	29.1	52.0
1970	24.015	61.7	38.3	41.6	18.318	74.3	25.7	52.0
1975	26.022	60.5	39.5	42.3	20.356	69.2	30.8	51.3
1980	30.535	53.0	47.0	37.9	23.707	61.7	38.3	46.3

1/ Real gross capital stocks for irrigation are the sum of irrigation investments since 1870 indexed to 1977 dollars, less all assets abandoned or fully depreciated. Assets only partly depreciated are included in the gross stock at their full cost in 1977 dollars.
2/ Real net capital values are the sum of irrigation investments made since 1870 less all accrued depreciation. Net capital values are less than gross stocks by the amount the assets and improvements still in service depreciated as of the year indicated.
3/, 4, 5/ See table 5.
6/ Percentages for project and onfarm capital stocks and net values add to 100. The Federal share can include both project and onfarm irrigation investments, as described in table 5.

Primary Sources: U.S. Bureau of the Census, Census of Agriculture, 1978, Vol. IV, "Irrigation," issued February 1982. Also part 9, Vol. II, "Irrigation and Drainage on Farms," 1974 Census. A major checkpoint for project facilities and investment, especially projects not constructed by the Bureau of Reclamation, was "Irrigation of Agricultural Lands," Vol. III, 1959 Census of Agriculture. All Censuses of Agriculture and Irrigation since 1900 were used.

Bureau of Reclamation, U.S. Department of the Interior: Annual Reports of the Commissioner, 1961-80, including Stat. App. on Finances and Physical Features." Also special historical (1903-80) expenditure data supplied by the Bureau's Operation and Maintenance Policy Staff.

U.S. Department of Agriculture: "Agricultural Statistics," (1981 and prior issues), plus various agency materials on irrigation and cost sharing, including the 1975-77 ERS Resource Economics Survey on investment and disinvestment. Also Irrigation Agriculture in the West by E. L. Greenshields, et al., Misc. Pub. 670, Office of Secretary, U.S. Dept. Agr., November 1948.

Brantwood Publications, Inc.: "1980 and 1981 Irrigation Surveys," Irrigation Journal, Vols. 30-(6)-31(6); also prior survey issues of the irrigation Journal and predecessors to 1956.

Table 7-- Bureau of Reclamation projects: cumulative capital investment in irrigation facilities and other multipurpose reclamation programs, with real capital stocks, net capital values, and acreage irrigated, United States, 1903-80

Year	Gross investment to date, all purposes: Historical dollars 1/	Gross investment to date, all purposes: Constant dollars 2/	Investment and gross capital in non-irrigation purposes 3/	Irrigation purposes and facilities: Gross capital stock 4/	Irrigation purposes and facilities: Net capital value 5/	Irrigation purposes and facilities: Capital share for irrigation 6/	Project acreages 7/ to date: Total irrigable acreage	Project acreages 7/ to date: Net acreage irrigated
	Billion dollars	-- Billion dollars (1977) --				--Percent--	-- Million acres --	
1905	0.028	0.125	--	0.125	0.1	)0.0	0.035	0.020
1910	.069	.544	0.011	.533	.533	98.0	.917	.473
1915	.122	1.254	.078	1.176	1.176	93.8	1.473	.857
1920	.166	1.496	.085	1.411	1.411	94.3	2.845	2.205
1925	.218	1.733	.118	1.615	1.615	93.2	3.143	2.339
1930	.274	1.954	.167	1.787	1.787	91.5	3.634	2.791
1935	.481	2.772	.656	2.116	2.116	76.4	3.614	2.936
1940	.747	4.506	1.574	2.932	2.932	65.1	4.180	3.391
1945	1.049	5.831	2.178	3.653	3.653	62.7	5.030	4.163
1950	1.921	8.234	3.523	4.711	4.704	57.2	6.025	5.077
1955	2.763	10.755	4.891	5.864	5.832	54.5	7.368	6.262
1960	3.608	12.738	5.808	6.930	6.875	54.4	8.171	6.900
1965	4.817	16.166	7.989	8.177	8.098	50.6	9.612	8.012
1970	5.898	18.524	9.312	9.212	9.094	49.7	10.198	8.570
1975	7.448	20.738	10.479	10.259	10.110	49.5	10.930	9.309
1980	10.420	22.284	11.390	10.894	10.720	48.9	11.943	10.092

1/ Gross capital investment for all purposes in historical dollars, taken as cumulative construction allotments from annual purpose allocations for 1903-80, as provided by the Bureau's Operation and Maintenance Policy Staff. Because of construction time requirements and other reasons, totals will generally exceed reported values of facilities actually in place.

2/ Gross capital investment in constant 1977 dollars approximates the cost of reproducing all existing Bureau irrigation and other project works at unit costs prevailing in 1977. Conversions to 1977 dollars based on the Engineering News Record (ENR) construction cost index (1900-24), the ENR index averaged with other water structure indexes (1925-46), and the Bureau's own composite indexes (1947-80) as published in Construction Cost Trends and the Dept. of Commerce's Survey of Current Business.

3/ Nonirrigation purposes include commercial hydropower, municipal/industrial water supply, flood control, navigation, fish and wildlife conservation; and recreation, health, and saftey.

4/ Gross capital stock for irrigation is equivalent to cumulative gross construction investment in 1977 dollars, excluding projects later canceled with Congressional approval.

5/ Net capital values were the same as gross stocks until 1949, when a program was initiated for the rehabilitation and betterment (R&B) of existing irrigation projects. Since 1950, net capital values are less than gross stocks by cumulative R&B expenditures. Thus, as of 1980, total R&B expenditures were about $174 million in real (1977) dollars, but about $105 million in historical dollars. In this study R&B expenditures are considered analogous to depreciation allowances because they impose a demand on investment budgets but create no new capacity.

6/ Irrigation's real share of gross stock for all purposes, col. 4/col. 2.

7/ Definitions for total irrigable acreage and net acreage irrigated are in table 3. Data taken directly from official Bureau of Reclamation reports.

Primary Sources: See table 6.

Table 8 -- Average annual gross and net real investment in gravity and sprinkler irrigation systems on farms, by 5-year periods, with end-of-period gross capital stocks and net capital values, United States, 1901-1980

Period	Gravity irrigation systems				Sprinkler irrigation systems			
	Gross annual investment 1/	Net annual investment 2/	Gross capital stock 3/	Net capital value 4/	Gross annual investment 1/	Net annual investment 2/	Gross capital stock 3/	Net capital value 4/
	-$Mil./yr. (1977 dol.)-		-$Billions-		-$Mil./yr. (1977 dol.)-		-$Billions-	
1901-05	17	5	0.396	0.241	--	--	--	--
1906-10	35	19	.496	.340	--	--	--	--
1911-15	37	17	.607	.429	--	--	--	--
1916-20	79	55	.927	.706	--	--	--	--
1921-25	21	16	.956	.786	--	--	--	--
1926-30	37	-1	1.055	.791	--	--	--	--
1931-35	5/ 18	-22	.963	.670	--	--	--	--
1936-40	18	-22	.872	.560	6/ 19	8	.381	.161
1941-45	153	118	1.243	1.154	43	24	.416	.282
1946-50	330	280	2.788	2.557	69	43	.587	.499
1951-55	243	129	3.820	3.204	109	64	1.121	.820
1956-60	216	66	4.476	3.535	133	63	1.674	.986
1961-65	136	-43	5.399	3.320	258	92	2.512	1.446
1966-70	188	-27	5.575	3.184	369	124	3.629	2.070
1971-75	37	-182	4.111	2.272	650	387	6.177	4.007
1976-80	91	-73	3.349	1.906	1,148	633	10.994	7.172

1/ Gross annual real investment in gravity or in sprinkler irrigation systems is 1/5th the sum for each 5-year period of gross annual investment, after each yearly amount, in current dollars if available, was indexed (deflated) to 1977 dollars. If annual data not available, estimated investment for the entire period was divided by 5.

2/ Net annual real investment is gross real investment less depreciation allowance on existing gross capital stocks. Average annual depreciation during each period for gravity or sprinkler systems can be determined by subtracting (algebraically) net annual investment from gross annual investment. For example:

Gravity system depreciation, 1976-80: 91-(-73) = 91 + 73 = $164 million/year (in 1977 dollars).
Sprinkler system depreciation, 1976-80: 1,148 - 633 = $515 million/year in 1977 dollars).

3/ Gross capital stocks are the estimated full original cost in 1977 dollars of gravity or sprinkler irrigation improvements, facilities and equipment still in use on farms, as of the last year of each indicated 5-year period.

4/ Net capital values are the estimated depreciated value in 1977 dollars of on-farm irrigation improvements, facilities and equipment in use as of the last yea of each indicated 5-year period.

5/ Gravity irrigation, annual gross investment, depreciation and net investment are averaged for years 1931 to 1940.

6/ Sprinkler irrigation gross annual investment, depreciation and net annual investment are averaged for years 1921 to 1940.

Table 9-- Per-acre real capital stocks, net capital values, and marginal investment costs for project and onfarm irrigation facilities, United States, 1900-80

Year	Project facilities: Project acreage served 1/	Project facilities: Net capital value 2/	Project facilities: Gross capital stock 2/	Project facilities: Marginal investment cost 3/, 4/	Onfarm irrigation facilities: Net acreage irrigated 1/	Onfarm irrigation facilities: Net capital value 2/	Onfarm irrigation facilities: Gross capital stock 2/	Onfarm irrigation facilities: Marginal investment cost 3/, 5/
	Million acres	---- Dollars per acre (1974) ----			Million acres	------- Dollars per acre -------		
1900	7.300	65	130	1,930	7.700	30	40	90
1905	8.160	190	255	1,890	8.640	30	45	100
1910	9.453	370	450	1,825	10.000	35	50	115
1915	10.412	490	610	1,780	11.195	40	55	130
1920	12.340	505	665	1,690	13.350	50	70	160
1925	12.574	460	705	1,680	13.815	55	70	170
1930	13.131	400	715	1,655	14.600	55	70	180
1935	11.781	415	760	1,720	13.000	45	70	155
1940	13.293	400	620	1,645	18.120	40	70	290
1945	15.247	390	525	1,555	20.665	70	80	335
1950	14.977	475	525	1,570	25.905	115	130	420
1955	17.122	495	550	1,470	30.275	130	165	490
1960	17.880	550	610	1,430	33.940	135	180	550
1965	19.422	600	670	1,360	37.470	130	210	600
1970	20.865	625	710	1,290	41.630	130	220	670
1975	21.578	650	730	1,260	46.250	135	220	745
1980	22.337	655	725	1,220	54.014	170	265	870

1/ Project and aggregate net acreages from table 3. Because all irrigation requires at least some onfarm investment, the onfarm capital stocks and net capital values apply to irrigated land, not to the land irrigated without projects.

2/ Net values and gross stocks in table 6 divided by respective acreage, rounded to nearest $5/acre.

3/ Marginal investment cost (MC) is the added capital investment historically associated with a 1-acre increase in the acreage irrigated. For example, let x = acres irrigated, Y = cumulative real investment, and t = any given year. Then an average measure of marginal cost between any two given years is $MC = (Y_t - Y_{t-1})/(x_t - x_{t-1})$. It corresponds to the mean acreage $(x_t + x_{t-1})/2$. A more precise measure of marginal cost is $MC = dY_t/dx_t$. It is the derivative of cumulative investment with respect to acreage.

4/ For project irrigation, marginal investment cost appears to have generally decreased over time and with acreage. It is computed from MC = $2,270.05 - 46.896x, with x in millions of acres served. MC is the derivative of a quadratic cumulative investment function Y_c, for the 17 observation years from 1900 to 1980. Conventional regression statistics are given in parentheses:

$$Y_c = a\,x^2 + b\,x + c = -23.448\,x^2 + 2{,}270.05\,x - 13{,}894.2$$

$$(N = 17,\ R^2 = 0.98,\ F(2,14) = 607,\ t_a = -2.24,\ t_b = 7.15,\ t_c = -6.16)$$

5/ For onfarm irrigation, marginal investment cost has increased. Letting x = millions of acres irrigated, it is derived from 16 first differences in investment and acreage:

$$MC = a\,x = 16.1364\,x;\ (N = 16,\ R^2 = 0.97,\ F(1,14) = 775,\ t_a = 53.83)$$

This is used only since 1940; costs before then are for gravity systems (table 10).

Table 10 -- Per-acre real capital stocks, net capital values, and marginal investment costs for gravity and sprinkler irrigation systems, United States, 1900-80

Year	Gravity irrigation				Sprinkler irrigation			
	Acres of gravity irrigation 1/	Net capital value 2/	Gross capital stock 2/	Marginal investment cost 3/, 4/	Acres of sprinkler irrigation 1/	Net capital value 2/	Gross capital stock 3/	Marginal investment cost 3/, 5/
	Million acres	---- Dollars per acre (1977) ----			Million acres	------- Dollars per acre -------		
1900	7.700	30	40	90	--	--	--	--
1905	8.640	30	45	100	--	--	--	--
1910	10.000	35	50	115	--	--	--	--
1915	11.195	40	55	130	--	--	--	--
1920	13.350	55	70	160	--	--	--	--
1925	13.815	55	70	170	--	--	--	--
1930	14.600	55	70	180	--	--	--	--
1935	13.000	45	65	155	--	--	--	--
1940	17.850	30	50	230	0.270	595	1,410	800
1945	20.250	55	60	270	.415	680	1,000	715
1950	24.915	100	110	365	.990	505	595	615
1955	28.005	115	135	435	2.270	360	495	585
1960	30.500	115	145	500	3.440	285	485	595
1965	31.940	105	170	535	5.530	260	455	630
1970	33.805	95	165	585	7.825	265	465	675
1975	34.150	65	120	595	12.100	330	510	760
1980	34.950	55	95	615	19.064	375	575	900

1/ Acreages irrigated with gravity and sprinkler systems are from table 4.
2/ Per-acre net values and gross stocks obtained by dividing the aggregate net capital values and gross stocks for gravity and sprinkler irrigation from table 8 by the respective acreages.
3/ Marginal investment cost explained in footnote 3, table 9.
4/ Gravity irrigation marginal investment cost from 1900 to 1980 was differentiated from a modified exponential cumulative investment function. Let Y_c = cumulative gross investment for gravity systems (in millions of 1977 dollars), and x = millions of acres with gravity irrigation systems. The least-squares equation for Y_c, using natural logarithms, is:

$$Y_c = a\ b\ x^{0.2}, \text{ or } \log Y_c = \log a + \log b\ x^{0.2} = -2.99960 + 5.94075\ x^{0.2}$$

$(N = 17,\ R^2 = 0.98,\ F(1, 15) = 786,\ t_{\log a} = -7.84,\ t_{\log b} = 28.04)$

Marginal cost is then differentiated from Y_c as $MC = (\log b)\ (5x^{0.8})^{-1}\ Y_c = 1.18815\ x^{-0.8}\ Y_c$

5/ Sprinkler irrigation marginal investment cost from 1940 to 1980 (9 observation years) was differentiated from a similar cumulative investment function. Let Y_c = cumulative investment in sprinkler systems (millions of dollars) and x = millions of acres. The selected least-squares equation for Y_c is:

$$Y_c = a\ b^{x^{0.2}}, \text{ or } \log Y_c = \log a + \log b\ x^{0.2} = 3.38834 + 3.41387\ x^{0.2}$$

$(N = 9,\ R^2 = 0.97,\ F(2, 6) = 681,\ t_{\log a} = 83.47,\ t_{\log b} = 16.96)$

Marginal cost is differentiated from Y_c as $MC = (\log b)\ (5x^{0.8})^{-1}\ Y_c = 0.68277\ x^{-0.8}\ Y_c$.

Table 11-- Sprinkler irrigation summary: Investment and acreage with capital values, and marginal investment cost, for water-supply components and by various types of sprinkler systems, United States, 1940-1980

Period	Average annual changes for indicated periods			Acreage and capital values to date			Percentage shares		Per-acre values and marginal investment cost		
	Gross annual investment 1/	Net annual investment 2/	Yearly acreage increase 3/	Acreage sprinkler irrigated 3/	Gross capital stock 4/	Net capital value 4/	Share of acreage irrigated 5/	Share of net capital	Net capital value	Gross capital stock	Marginal investment cost 9/
	-$Mil./yr. (1977 dol.)-		-Thous. ac.-	-Mil. ac.-	-$Mil. (1977 dol.)-		-Percent-		-1977 dollars per acre-		
Part A : All sprinkler irrigation facilities on farms; $9.066 bil. invested to 1980 ($14.298 bil. in 1977 dollars)											
1921-40	19	8	14	0.270	381	169	1.5	6/ 22.3	595	1,410	10/ 800
1941-45	43	24	29	.415	416	282	2.0	19.6	680	1,000	715
1946-50	69	43	115	.990	587	499	3.8	16.3	505	595	615
1951-55	109	64	256	2.270	1,121	820	7.5	20.4	360	495	585
1956-60	133	63	234	3.440	1,674	986	10.1	21.8	285	485	595
1961-65	258	92	418	5.530	2,512	1,446	14.8	30.3	260	455	630
1966-70	369	124	459	7.825	3,629	2,070	18.8	39.5	265	465	675
1971-75	650	387	855	12.100	6,177	4,007	26.2	63.8	330	510	760
1976-80	1,148	633	1,393	19.064	10,994	7,172	35.3	79.0	375	575	900
Part B: Water supplies and pumping equipment for sprinkler systems; $3.539 bil. invested to 1980 ($5.370 bil. in 1977 dollars)											
1921-40	2	1	14	0.270	33	20	1.5	7/ 11.8	75	120	11/ 210
1941-45	6	4	29	.415	50	42	2.0	14.9	100	120	190
1946-50	18	15	115	.990	127	120	3.8	24.0	120	130	175
1951-55	41	35	256	2.270	332	299	7.5	36.5	130	145	190
1956-60	48	33	234	3.440	571	466	10.1	47.3	135	165	205
1961-65	95	69	418	5.530	1,017	813	14.8	56.2	145	185	235
1966-70	134	88	459	7.825	1,601	1,253	18.8	60.5	160	205	270
1971-75	271	197	855	12.100	2,748	2,239	26.2	55.9	185	225	325
1976-80	451	235	1,393	19.064	4,764	3,867	35.3	53.9	200	250	415
Part C: Sprinkler distribution, all types systems; $5.527 bil. invested to 1980 ($8.928 bil. in 1977 dollars)											
1921-40	17	7	14	0.270	348	149	1.5	7/ 88.2	520	1,290	12/ 635
1941-45	37	19	29	.415	366	240	2.0	85.1	575	880	555
1946-50	51	27	115	.990	460	379	3.8	76.0	385	465	445
1951-55	68	28	256	2.270	789	521	7.5	63.5	230	350	395
1956-60	85	0	234	3.440	1,103	520	10.1	52.7	150	320	385
1961-65	162	22	418	5.530	1,495	633	14.8	43.8	115	270	385
1966-70	235	36	459	7.825	2,028	817	18.8	39.5	105	260	395
1971-75	379	190	855	12.100	3,429	1,768	26.2	44.1	145	285	420
1976-80	697	307	1,393	19.064	6,230	3,305	35.3	46.1	175	325	470

Footnotes at end of table.

Continued --

Table 11--Sprinkler irrigation summary: Investment and acreage with capital values, and marginal investment cost, for water-supply components and by various types of sprinkler systems, Unites States, 1940-1980--Continued

Period	Average annual changes for indicated periods: Gross annual investment 1/	Net annual investment 2/	Yearly acreage increase 3/	Acreage and capital values to date: Acreage sprinkler irrigated 3/	Gross capital stock 4/	Net capital value 4/	Percentage shares: Share of acreage irrigated 5/	Share of net capital	Per-acre values and marginal investment cost: Net capital value	Gross capital stock	Marginal investment cost 9/
	-$Mil./yr. (1977 dol.)-		-Thous. ac.-	-Mil. ac.-	-$Mil. (1977 dol.)-		-Percent-		-1977 dollars per acre-		
Part D: Permanent and solid-set sprinkler systems; $749 mil. invested to 1980 ($1.699 bil. in 1977 dollars)											
1921-40	17	7	14	0.270	348	141	100.0	8/ 100.0	520	1,288	13/ 1,425
1941-45	37	19	29	.451	366	240	100.0	100.0	575	880	1,215
1946-50	31	13	27	.550	362	306	55.6	80.7	555	660	1,069
1951-55	20	1	19	.645	450	315	28.4	60.5	490	700	990
1956-60	20	-2	22	.755	540	305	21.9	58.7	405	715	925
1961-65	22	-4	26	.885	466	283	16.0	44.7	320	525	865
1966-70	35	12	43	1.100	486	344	14.1	42.1	315	440	820
1971-75	46	22	55	1.375	617	454	11.4	25.7	330	450	825
1976-80	56	25	65	1.702	796	581	8.9	17.6	340	470	950
Part E: Portable hand-moved sprinkler systems; $945 mil. invested to 1980 ($1.979 bil. in 1977 dollars)											
1946-50	19	14	88	0.440	8	73	44.4	8/ 19.3	165	225	14/ 135
1951-55	37	19	190	1.390	287	168	61.2	32.3	120	210	265
1956-60	57	0	177	2.275	475	166	66.1	31.9	75	210	350
1961-65	95	6	243	3.490	762	199	63.1	31.4	60	220	400
1966-70	78	-22	102	4.000	870	87	51.1	10.6	25	220	400
1971-75	57	-17	-20	3.900	682	0	32.2	0	0	175	400
1976-80	49	0	-52	3.641	633	0	19.0	0	0	175	400
Part F: Tows, drags, and wheel-roll sprinkler systems; $977 mil. invested to 1980 ($1.385 bil. in 1977 dollars)											
1951-55	5	3	25	0.125	26	17	5.5	8/ 3.3	135	210	15/ 215
1956-60	3	0	19	.220	44	21	6.4	4.0	95	200	220
1961-65	14	1	33	.385	89	26	7.0	4.1	70	230	230
1966-70	30	14	108	.925	224	98	11.8	12.0	105	240	265
1971-75	80	27	238	2.115	556	233	17.5	13.2	110	265	355
1976-80	142	31	364	3.936	1,116	391	20.6	11.8	100	285	550
Part G: Self-propelled sprinkler systems, other than center-pivots; $204 mil. invested to 1980 ($344 mil. in 1977 dollars)											
1951-55	5	4	22	0.110	26	21	4.8	8/ 4.0	190	235	16/ 310
1956-60	3	1	16	.190	44	28	5.5	5.4	150	230	310
1961-65	7	3	28	.330	90	43	6.0	6.8	130	275	310
1966-70	14	2	40	.530	125	55	6.8	6.7	105	235	310
1971-75	18	4	64	.850	197	75	7.0	4.2	90	230	310
1976-80	20	-3	56	1.134	263	61	5.9	1.8	55	230	310

Footnotes at end of table.

Continued --

Table 11--Sprinkler irrigation summary: Investment and acreage with capital values, and marginal investment cost, for water-supply components and by various types of sprinkler systems, United States, 1940-1980

Period	Average annual changes for indicated periods: Gross annual investment 1/	Net annual investment 2/	Yearly acreage increase 3/	Acreage and capital values to date: Acreage sprinkler irrigated 3/	Gross capital stock 4/	Net capital value 4/	Percentage shares: Share of acreage irrigated 5/	Share of net capital	Per-acre values and marginal investment cost: Net capital value	Gross capital stock	Marginal investment cost 9/
	-$Mil./yr. (1977) dol.)-		-Thous. ac.-	-Mil. ac.-	-$Mil. (1977 dol.)-		-Percent-		-1977 dollars per acre-		
Part H: Center-pivot sprinkler systems; $2.258 bil. invested to 1980 ($2.988 bil. in 1977 dollars)											
1961-65	19	16	88	.440	98	82	8.0	8/ 13.0	185	255	17/ 235
1966-70	45	30	166	1.270	323	233	16.2	28.5	185	255	290
1971-75	159	105	480	3.670	1,121	762	30.3	43.1	210	305	365
1976-80	373	205	917	8.255	2,889	1,791	43.3	54.2	215	350	435
Part I: Drip irrigation systems; $394 mil. invested to 1980 ($533 mil. in 1977 dollars)											
1971-75	51	48	38	.190	256	244	1.6	8/ 13.8	1,285	1,350	18/ 1,350
1976-80	55	47	41	.396	533	481	2.1	11.9	1,220	1,350	1,350

1/ Gross annual real investment is gross investment in current dollars indexed to an implicit price deflator (IPD) for producers' durable farm equipment.

2/ Net annual real investment is gross annual investment less an annual depreciation allowance on gross capital stocks. Average service lives used in figuring depreciation are: 25 years for wells and stream improvements for water supply; from 9 to 20 years for pumps and power units, depending on type; 20 years for permanent and solid-set sprinkler distribution systems; 15 years for all self-propelled sprinkler systems; and 10 years for hand-moved, towed, or wheel-roll sprinkler systems.

3/ Sprinkler acreages and annual changes in acreage are compared with gravity irrigation in table 4.

4/ Capital values refer to the closing year of each period. The gross capital stock is the sum of gross investments to date in 1977 dollars, less prior investments that have since fully depreciated. Net capital value is the remaining depreciated value of the gross capital stock.

5/ Acreage shares in parts A, B, and C are for sprinkler irrigation compared to all irrigation. Shares for the different sprinkler systems in part D through part I are relative to the total sprinkler irrigated acreage in part C.

6/ In part A, capital shares are relative to totals for all onfarm irrigation capital. Balances are for gravity irrigation (see table 8).

7/ In parts B and C, capital shares are relative to totals for all sprinkler irrigation capital.

8/ In part D through part F, capital shares are relative to totals for all types of sprinkler distribution systems.

Continued --

9/ Marginal investment cost (MC) is the added real capital investment historically associated with a 1-acre increase in the acreage supplied with water and pumping equipment, and/or irrigated with a particular type of sprinkler system. In notes below Y_c is cumulative real investment to date, in millions of 1977 dollars, and x is the area currently irrigated with the described facilities or systems, in millions of acres. Ordinary least-squares regression statistics are in parentheses after each fitted cumulative investment or marginal cost equation. All logarithms are to the base e = 2.71828.

Annual data on acreages sprinkler irrigated are available in trade sources. However, there is considerable year-to-year and State-by-State variation in how sprinkler systems have been reported and classified by type. This problem, along with the paucity of corresponding annual investment data, explains why marginal investment costs have been analyzed for 5-year intervals rather than annually.

10/ The average marginal cost for sprinkler irrigation decreased until about 1955, and thereafter increased. Marginal cost is obtained indirectly from the cumulative investment function Y_c:

$$Y_c = a\, b^{x^{0.2}}, \text{ or } \log_e Y_c = \log a + (\log b)\, x^{0.2} = 3.38834 + 3.41387\, x^{0.2}$$

$$(N = 9,\ R^2 = 0.97,\ F(2, 6) = 681,\ t_{\log a} = 83.47,\ t_{\log b} = 16.96)$$

Marginal cost is differentiated from Y_c as $MC = dY_c/dx = (\log b)\,(5\, x^{0.8})^{-1}\, Y_c = 0.68277\, x^{-0.8}\, Y_c$

11/ The marginal cost of water supply development and pumping equipment for sprinkler irrigation, abstracting from the many different types of water distribution systems in use, appears to have decreased until the early fifties. It then increased significantly. Marginal cost (MC) for water supply is estimated directly, from eight first differences in cumulative real investment and acreage for the nine observavation years from 1940-1980:

$$MC = c\, x^{a \log x}, \text{ or } \log_e MC = a\,(\log x)^2 + \log c = 0.098831\,(\log x)^2 + 5.174118$$

$$(N = 8,\ R^2 = 0.83,\ F(1, 6) = 35,\ t_a = 5.95,\ t_{\log c} = 76.97)$$

12/ The average marginal cost of sprinkler distribution systems appears to have decreased until the mid-sixties but has since increased. Marginal cost in this case is obtained indirectly from a cumulative investment function in Y_c:

$$Y_c = a\, b^{x^{0.2}}, \text{ or } \log Y_c = \log a + \log b\, x^{0.2} = 3.60416 + 3.00459\, x^{0.2}$$

$$(N = 9,\ R^2 = 0.99,\ F(1, 7) = 931,\ t_{\log a} = 27.85,\ t_{\log b} = 30.51)$$

Marginal cost is differentiated from Y_c as $MC = dY_c/dx = (\log b)\,(5\, x^{0.8})^{-1}\, Y_c = 0.600918\, x^{-0.8}\, Y_c$

13/ For permanent sprinkler systems, marginal investment cost appears to have decreased from around $1,400 per acre in 1940 to $820 per acre in 1970. By 1980 it had increased $950 per acre. Marginal cost (MC) is determined directly from eight first differences in cumulative investment Y_c and acreage x:

$$\log_e MC = a\, x^2 + b\, x + c = 0.64590\, x^2 - 1.55528\, x + 7.05005$$

$$(N = 8,\ R^2 = 0.97,\ F(2, 5) = 96,\ t_a = 7.75,\ t_b = -9.76,\ t_c, = 114.36)$$

14/ Marginal investment cost for hand-moved sprinkler systems, as determined directly from six first differences in cumulative investment and acreage, was about $135 per acre in 1950. It increased to about $400 per acre by 1965. In this study it is assumed to have at least remained at that level, recognizing the decrease since 1970 in the acreage sprinkler irrigated wtih hand-moved systems:

$$MC = a\, x^2 + b\, x + c = -24.9417\, x^2 + 183.737\, x + 59.8659, \text{ (maximum x = 4 million acres, as reached about 1970)}$$

$$(N = 6,\ R^2 = 0.93,\ F(2, 3) = 33,\ t_a = -5.44,\ t_b = 6.51,\ t_c = 1.60)$$

Continued--

15/ For the various towed or wheel-roll sprinkler systems marginal cost appears to have increased from about $215 per acre in 1955 to $550 per acre in 1980. Marginal cost is estimated from five first differences in cumulative investment and acreage:

$$\log_e MC = a\,x + b = 0.247082\,x + 4.75822, \quad (N = 5,\ R^2 = 0.84,\ F(1, 3) = 16,\ t_a = 3.95,\ t_b = 49.29)$$

16/ For self-propelled sprinkler systems other than center-pivot systems, marginal cost appears to have held steady at about $310 per acre since 1950. In this case the constant marginal cost is a or the slope coefficient for x in the cumulative investment function Y_c:

$$Y_c = a\,x + b = 310.81x - 7.89933, \quad (N = 6,\ R^2 = 0.99,\ F(1, 4) = 1{,}475,\ t_a = 38.40,\ t_b = -2.74)$$

17/ For center-pivot sprinkler systems marginal cost appears to have increased from about $235 per acre in 1965 to $435 per acre by 1980. From only three first differences taken in cumulative investment and acreage in the 15 years from 1965 to 1980, marginal cost is:

$$MC = b\,x^a, \text{ or } \log_e MC = a \log x + b = 0.210373 \log x + 5.62785$$

$$(N = 3,\ R^2 = 0.99,\ F(1, 1) = 507,\ t_a = 22.53,\ t_b = 466.00)$$

18/ Information is not adequate for estimating trends in marginal cost for drip irrigation. The $1,350 per acre average is gross real investment for the years 1976-80, divided by the increase in acreage. It is also equal to gross capital stocks per acre: no drip systems have depreciated fully.

Primary Sources: Sprinkler irrigated acreage is taken with some adejustment from various quinquennial Censuses of Agriculture from 1949 to 1978, from decennial Censuses of Irrigation from 1949 to 1978, and from annual "Irrigation Surveys from 1956 to 1980 as published in the Irrigation Journal and predecessor publications. Acreage by type of distribution system is based mainly on State survey reports in the Irrigation Journal. Investment costs for various sprinkler systems and components are compiled and standardized from various trade sources plus about 50 State and Federal research bulletins on the engineering and economic aspects of sprinkler system design and operation. A detailed earlier listing is in "Agriculture, Natural Resources and Capital Growth: A Bibliography," Working Paper No. 45, Natural Resource Economics Division, Econ. Res. Ser., U.S. Dept. Agr., April 1978.

Table 12 --Farmland drained with and without project drainage facilities, with average annual changes in acreage, United States, 1900-80

Year	Farmland currently drained: Net acreage drained 1/	Drained within projects 2/	Drained without projects 3/	Acreage shares: Drained within projects	Drained without projects	Average annual change, past 5 years: All farm drainage	Drained within projects	Drained without projects
	------ Million acres ------			---- Percent ----		------ Thousand acres ------		
1900	6.295	6.265	0.030	99.5	0.5	--	--	--
1905	11.677	11.620	.057	99.5	.5	1,076	1,071	5
1910	22.305	22.190	.115	99.5	.5	2,126	2,114	12
1915	35.045	34.830	.215	99.4	.6	2,548	2,528	20
1920	49.445	48.154	1.291	97.4	2.6	2,880	2,665	215
1925	47.563	45.185	2.378	95.0	5.0	-376	-593	217
1930	49.363	45.414	3.949	92.0	8.0	360	46	314
1935	45.850	41.265	4.585	90.0	10.0	-703	-830	127
1940	45.437	39.985	5.452	88.0	12.0	-83	-90	173
1945	50.324	41.266	9.058	82.0	18.0	977	257	720
1950	69.929	48.950	20.979	70.0	30.0	3,921	1,537	2,384
1955	78.865	55.954	22.911	70.9	29.1	1,787	1,401	386
1960	86.607	63.223	23.384	73.0	27.0	1,548	1,454	94
1965	93.643	63.286	30.357	67.6	32.4	1,407	13	1,394
1970	99.084	65.121	33.963	65.7	34.3	1,088	367	721
1975	103.400	66.553	36.847	64.4	35.6	863	286	577
1980	107.483	67.351	40.132	62.7	37.3	817	160	657

1/ The net acreage of farmland currently drained follows the most recent (1978) census definition which refers to the area of agricultural land benefited to some extent by water removal to improve the soil environment for plant growth. Both surface and subsurface drainage are included (ditches, title or other subsurface drains, dikes, pumping plants, and land grading). Net acreages drained with surface versus subsurface systems are given in table 13.

Drainage that is a normal aspect of irrigation is excluded. Special drainage in irrigation systems installed for salinity control and temporary control of high water tables was included in the 1978 drainage census as being drainage. In this study, however, the special investments in drainage closely associated with irrigation are included with irrigation alone in estimating natural resource capital stocks and net values. As of 1980, roughly 5 million acres of irrigated land required such special drainage.

2/ Includes only agricultural land benefiting from public or other group drainage facilities, as defined in the 1959 Census of Drainage. The net service area for projects was determined by beginning with all land drained within organized drainage districts, county drains, other drainage enterprises, and irrigation enterprises active in special drainage, then deducting nonagricultural lands drained within enterprises, and also farmsteads, roads, wastland, and timber or brushlands within the farms serviced by drainage enterprises. The censuses of agriculture and drainage were the primary, though not exclusive sources, of required acreage information on project drainage, particularly, for years since 1959. Consequently, the acreages may not agree completely with census data for census years.

3/ Estimated from the censuses of agriculture and drainage, Agricultural Conservation Program reports, and Soil Conservation Service progress reports.

Table 13 --Farmland currently drained with surface versus subsurface drainage systems, with average annual acreage changes and estimates for systems not fully depreciated, United States, 1900-80

Year	Farmland currently drained		Average shares		Annual change, past 5 years		Undepreciated drainage 3/	
	Surface drainage systems	Subsurface drainage systems	Surface drainage systems	Subsurface drainage systems	Surface drainage systems	Subsurface drainage systems	Surface drainage systems	Subsurface drainage systems
	--- Million acres --- 1/		--- Percent ---		--- Thousand acres --- 2/		--- Million acres ---	
1900	5.271	1.024	83.7	16.3	--	--	3.975	1.014
1905	9.775	1.902	83.7	16.3	900	176	7.447	1.877
1910	18.673	3.632	83.7	16.3	1,780	346	15.313	3.572
1915	29.344	5.701	83.7	16.3	2,134	414	25.029	5.541
1920	43.452	5.993	87.9	12.1	2,822	58	38.131	5.573
1925	41.420	6.143	87.1	12.9	-406	30	41.412	6.143
1930	42.676	6.687	86.5	13.5	251	109	38.514	6.010
1935	38.606	7.244	84.2	15.8	-814	111	32.697	6.118
1940	36.532	8.905	80.4	19.6	-415	332	19.298	4.711
1945	40.769	9.555	81.0	19.0	847	130	15.800	3.291
1950	57.980	11.949	82.9	17.1	3,442	479	22.849	5.394
1955	64.995	13.670	82.7	17.3	1,443	344	29.172	6.510
1960	70.784	15.823	81.7	18.3	1,117	431	34.252	7.550
1965	76.013	17.630	81.2	18.8	1,046	361	35.244	9.048
1970	79.753	19.331	80.5	19.5	748	340	21.773	10.426
1975	82.583	20.817	79.9	20.1	566	297	17.588	11.912
1980	84.715	22.768	78.8	21.2	427	390	13.931	13.863

1/ Acreages for surface and subsurface drainage add to the overall net acreage drained as shown in table 12.

2/ Rates of increase or decrease for surface and subsurface drainage add to the overall change for all farm drainage as shown in table 1.

3/ Undepreciated drainage refers to surface drainage systems in place for less than 20 years, to those subsurface systems in place for less than 30 years if installed before 1940, or to those subsurface systems in place for less than 40 years if installed in 1940 or thereafter. Note that by 1980, surface and subsurface systems were about equal in importance on an undepreciated basis, even though surface systems were still in much wider use as indicated by the acreages and percentage distributions for current drainage (cols. 1 to 4). Such a breakdown is useful as an overall indicator of general age and condition of farm drainage systems and was helpful for measuring active gross capital stocks and net capital values.

Table 14 --Average annual gross and net real capital investment in project and onfarm drainage, with Federal investments, United States, by 5-year periods 1901-80

Period	Gross annual drainage investment 1/				Net annual drainage investment 2/			
	All investment	Project facilities 3/	On-farm facilities 4/	Federal investment 5/	All investment	Project facilities	On-farm facilities	Federal investment
	Million dollars 1977							
1901-05	161	134	27	--	131	113	18	--
1906-10	342	295	47	--	292	262	30	--
1911-15	261	167	94	--	210	163	47	--
1916-20	229	199	30	--	153	164	-11	--
1921-25	206	176	30	--	111	121	-10	--
1926-30	242	198	44	--	134	131	3	--
1931-35	53	40	13	--	-74	-50	-24	--
1936-40	15	4	11	--	-72	-53	-19	--
1941-45	85	9	76	6	-1	-50	49	3
1946-50	325	46	279	31	216	-13	229	29
1951-55	233	45	188	28	87	-11	98	18
1956-60	274	48	226	39	94	-12	106	25
1961-65	292	56	236	42	77	-5	82	20
1966-70	263	58	205	25	37	-3	40	-1
1971-75	199	48	151	10	-34	-8	-26	-18
1976-80	175	30	145	10	-55	-25	-30	-17

1/ Gross real investment in drainage is 20 percent of the sum for the period of annual drainage investments after each yearly amount in current dollars was indexed (deflated) to 1977 price levels. Information developed by 5-year intervals if annual data not available.
2/ Net real investment is gross investment less depreciated allowances on existing gross capital stocks. Average depreciation for each component and period can be determined by subtracting net investment rates from corresponding gross rates. For example:
All depreciation, 1966-70: $263 - $37 = $226 million/year (in 1977 dollars).
All depreciation, 1976-80: $175 - ($55) = $175 + 55 = $280 million/year (in 1977 dollars).
3/ Includes capital investments by any drainage enterprise or organization formed to assist in the removal by artificial means of excess water to improve the condition of land used or to be used for agriculture (Bureau of Census definition). The two dominant types of drainage enterprises in the United States are the drainage district and the county drain. There are also township drains, State drainage projects, commercial enterprises developing wetlands for sale, small cooperatives and mutuals, and a few partnerships and corporations. Irrigation districts can be involved in drainage too, but major drainage investments associated with or required because of sustained irrigation are counted under irrigation capital.
4/ Covers all onfarm investments for drainage improvements and equipment, including land preparation, ditches, tile, or other buried materials, drainage wells, pumps, and so forth.
5/ Federal capital investments for drainage limited to some cost-sharing assistance provided under the USDA's Agricultural Conservation Program. Further, this assistance has been phased out gradually since the mid sixties.

Table 15 --Real gross capital stocks and net capital values for project and onfarm drainage assets, with federally financed shares, United States, 1900-80

Year	Gross capital stock, drainage facilities 1/: All drainage capital	Gross: Project facilities 3/	Gross: Onfarm systems 4/	Gross: Federal share 5/	Net capital value, drainage facilities 2/: All drainage capital	Net: Project facilities 3/	Net: Onfarm systems 4/	Net: Federal share 5/
	Billion dols. (1977)	--- Percent --- 6/			Billion dols. (1977)	--- Percent --- 6/		
1900	1.560	88.3	11.7	--	0.988	88.2	11.8	--
1905	2.345	87.3	12.7	--	1.645	87.3	12.7	--
1910	4.038	87.2	12.8	--	3.107	88.4	11.6	--
1915	5.318	83.8	16.2	--	4.157	85.7	14.3	--
1920	6.415	85.0	15.0	--	4.924	89.0	11.0	--
1925	7.363	86.0	14.0	--	5.478	91.1	8.9	--
1930	8.414	87.0	13.0	--	6.149	91.8	8.2	--
1935	8.153	88.8	11.2	--	5.778	93.4	6.6	--
1940	7.878	90.8	9.2	--	5.418	94.6	5.4	--
1945	7.902	89.7	10.3	0.4	5.411	90.1	9.9	0.6
1950	9.221	78.0	22.0	2.0	6.492	74.1	25.9	2.6
1955	10.273	71.4	28.6	3.2	6.925	68.7	31.3	3.8
1960	11.410	65.4	34.6	4.6	7.396	63.5	36.5	5.3
1965	12.370	60.0	40.0	5.9	7.782	60.0	40.0	6.3
1970	12.258	57.0	43.0	7.0	7.965	58.4	41.6	6.0
1975	12.458	54.1	45.9	7.1	7.793	59.1	40.9	5.0
1980	12.664	51.3	48.7	6.2	7.520	59.6	40.4	4.1

1/ Real gross capital stocks for drainage are the sum of drainage investments since 1855 indexed to 1977 dollars, less all those created assets and improvements abandoned and or fully depreciated. Assets only partly depreciated are included in the gross stocks at their full cost in 1977 dollars.
2/ Real net capital values are the sum of investments since 1855 less all accrued depreciation. Net capital values are less than gross stocks by the amount by which just those assets and improvements still in service had depreciated as of the year indicated.
3/, 4/, 5/, See table 14.
6/ Percentages for project and onfarm capital stocks and net values add to 100. The Federal share is limited to onfarm drainage improvements, for which some cost-sharing was provided under USDA's Agricultural Conservation Program.

SOURCES: U.S. Bureau of the Census: 1977 Census of Agriculture. Vol. 5, pt. 5 "Drainage of Agricultural Lands," issued October 1981, also pt. 9 Vol. II, of 1974 Census of Irrigation and Drainage on Farms. Major checkpoints for project acreage and drainage investments going back to before 1870 were the 1940 U.S. Census reports "Drainage of Agricultural Lands: U.S. Summary," and "Drainage of Alluvial Lands," both published in 1943.

U.S. Department of Agriculture: "Agricultural Statistics" (annual 1981 and prior issues), plus various other agency materials dealing with onfarm drainage improvements and group drainage facilities or organizations, including the ERS Resource Economics Survey, 1975-77, on land drainage and investment. Special drainage cost data were also supplied by the Agricultural Stabilization and Conservation Service and the Soil Conservation Service.

Table 16 --Average annual gross and net real investment in surface and subsurface drainage systems on farms, by 5-year periods, with end-of-period gross capital stocks and net capital values, United States, 1901-80

Period	Surface drainage systems				Subsurface drainage systems			
	Gross annual investment 1/	Net annual investment 2/	Gross capital stock 3/	Net capital value 4/	Gross annual investment 1/	Net annual investment 2/	Gross capital stock 3/	Net capital value 4/
	-- Million dols. (1977) --		-- Billion dollars --		-- Million dols. (1977) --		-- Billion dollars --	
1901-05	10	5	0.091	0.049	16	12	0.207	0.160
1906-10	23	13	.195	.116	23	16	.319	.243
1911-15	31	14	.338	.188	43	32	.521	.405
1916-20	24	2	.448	.200	4	-13	.511	.340
1921-25	13	-9	.464	.151	16	0	.563	.337
1926-30	20	-1	.451	.143	23	4	.638	.359
1931-35	1	-13	.303	.074	11	-10	.608	.309
1936-40	1	-7	.185	.035	9	-10	.537	.255
1941-45	25	19	.236	.131	50	29	.578	.401
1946-50	132	111	.804	.686	146	118	1.216	.994
1951-55	59	13	1.093	.753	128	84	1.849	1.417
1956-60	56	-3	1.369	.737	169	109	2.581	1.986
1961-65	62	-11	1.551	.678	173	94	3.393	2.438
1966-70	46	-21	1.121	.569	158	61	4.147	2.747
1971-75	32	-20	0.986	.467	118	-6	4.730	2.717
1976-80	22	-25	.813	.341	123	-5	5.346	2.693

1/ Gross annual real investment in drainage systems is 20 percent of the sum for each 5-year period of annual investment, after each yearly amount in current dollars was indexed (deflated) to 1977 dollars. If annual data were not available, estimated total investment for the period was divided by 5 and indexed to 1977 dollars.
2/ Net annual investment is gross real investment less the annual depreciation allowance on existing gross capital stocks. Average annual depreciation during each period for surface or subsurface systems can be determined by subtracting net annual investment from gross annual investment.
For example:

Surface drainage depreciation, 1951-55 \$59-\$13 = \$46 million/year (in 1977 dollars.)
Surface drainage depreciation, 1976-80 \$22- (-\$25) = \$22 + \$25 = \$47 million/year (in 1977 dollars).

3/ Gross capital stocks are the original cost in 1977 dollars of surface or subsurface drainage improvements, facilities, and equipment still in use on farms as of the last year of each indicated 5-year period. In a general way, these gross stocks and the net capital values match the undepreciated acreages given in table 13, although much more land than this may actually be drained.
4/ Net capital values are the depreciated value in 1977 dollars of on-farm surface or subsurface drainage improvements, facilities, and equipment in use as of the year of each indicated 5-year period.

Table 17 --Per-acre capital stocks, net capital values, and marginal investment costs for project and onfarm drainage facilities, United States, 1900-80

Year	Project facilities: Project acreage served 1/	Project facilities: Net capital value 2/	Project facilities: Gross capital stock 2/	Project facilities: Marginal investment cost 3/, 4/	On-farm facilities: Acreage currently drained 1/	On-farm facilities: Net capital value 2/	On-farm facilities: Gross capital stock 2/	On-farm facilities: Marginal investment cost 3/, 5/
	Million acres	-- Dols. per acre-1977 --			Million acres	-- Dols. per acre-1977 --		
1900	6.265	140	220	220	6.295	20	30	58
1905	11.620	125	175	175	11.677	20	25	58
1910	22.190	125	160	160	22.305	15	25	61
1915	34.830	100	130	145	35.045	15	25	79
1920	48.154	90	115	145	49.445	10	20	40
1925	45.185	110	140	145	47.563	10	20	--
1930	45.414	125	160	145	49.363	10	20	--
1935	41.265	130	175	145	45.850	8	20	--
1940	39.985	130	180	145	45.437	6	15	--
1945	41.266	120	170	145	50.324	10	15	--
1950	48.950	100	150	145	69.929	25	30	76
1955	55.954	85	130	145	78.865	30	35	114
1960	63.223	75	120	145	86.607	30	45	150
1965	63.286	75	115	145	93.643	35	55	145
1970	65.121	70	105	145	99.084	35	55	164
1975	66.553	70	100	145	103.400	30	55	172
1980	67.351	70	95	145	107.483	30	55	206

1/ Project service and aggregate acreage currently drained are from table 12. As some onfarm facilities are required for all drainage, the net capital values, gross stocks, and marginal costs apply to all farm drainage, not to just the acreage not served by projects.
2/ Net capital values and gross stocks as determined in table 13 divided by the respective acreages. Per-acre data are rounded to the nearest $5, unless under $10.
3/ Marginal investment cost (MC) is the added gross investment historically associated with a 1-acre increase in the acreage drained in a given year. Also see note 3/, table 9.
4/ For project drainage, real marginal investment cost appears to have been constant since about 1915, at about $145 per added acre served. Higher marginal costs, equivalent to per-acre gross stock values, are shown up to 1910. This is consistent with the fact that drainage in the U.S. expanded very rapidly between 1870 and 1920, implying some significant economies of scale and decreases in the unit (per-acre) costs of developing projects.

The constant marginal investment of $145 per added acre for project drainage is the coefficient a in the cumulative investment function Y_c for the 17 observation years from 1900 to 1980. Y_c is in millions of 1977 dollars and x is in millions of acres served:

$$Y_c = a\,x = 144.337\,x;\ (N=17,\ R^2 = 0.85,\ F(1,\ 15) = 96,\ t_a = 30.57)$$

5/ From 1900-20 and 1946-80, average onfarm marginal cost is the weighted mean of surface and subsurface system marginal cost shown in table 18, the weights being respective acreage increases per year by 5-year periods in table 13. Average onfarm marginal costs are not shown for 1921-45; they would range between marginal surface and subsurface system costs shown in table 18.

Table 18 --Per-acre capital stocks, net capital values, and marginal investment costs for surface and subsurface farm drainage systems, United States, 1900-80

Year	Surface drainage: Acres of surface drainage 1/	Surface drainage: Net capital value 2/	Surface drainage: Gross capital stock 2/	Surface drainage: Marginal investment cost 3/, 4/	Subsurface drainage: Acres of surface drainage 1/	Subsurface drainage: Net capital value 2/	Subsurface drainage: Gross capital stock 2/	Subsurface drainage: Marginal investment cost 3/, 5/
	Million acres	-- Dols. per acre-1977 --			Million acres	-- Dols. per acre-1977 --		
1900	5.271	4	10	48	1.024	95	125	125
1905	9.775	5	9	53	1.902	85	110	110
1910	18.673	6	10	57	3.632	65	90	110
1915	29.344	6	10	37	5.701	70	90	190
1920	43.452	5	10	36	5.993	55	85	200
1925	41.420	4	10	39	6.143	55	90	205
1930	42.676	3	10	38	6.687	55	95	224
1935	38.606	2	8	38	7.244	40	85	245
1940	36.532	1	5	36	8.905	30	60	290
1945	40.769	3	6	37	9.555	40	60	310
1950	57.980	10	15	42	11.949	85	100	360
1955	64.995	10	15	48	13.670	105	135	385
1960	70.784	10	20	50	15.823	125	165	405
1965	76.013	9	20	53	17.630	140	190	410
1970	79.753	7	15	55	19.331	140	215	405
1975	82.583	6	10	56	20.817	130	225	395
1980	84.715	4	10	58	22.768	120	235	370

1/ Acreages currently drained with surface and subsurface systems are from table 13.
2/ Per-acre values are the aggregate net capital values and gross stocks found from table 16 divided by currently acreage drained. As drainage systems on much of this land have been fully depreciated, the per-acre averages may appear unduly low. To obtain averages applicable only to relatively new systems, divide gross capital stocks and net values by the undepreciated acreages in table 11.
3/ Marginal investment costs (MC) is the added gross real capital investment historically associated with a 1-acre increase in the acreage drained by surface or subsurface methods.
4/ MC's from 1915 are computed from a regression of average available field cost per acre (in 1977 dollars) on the total acreage (x) with surface systems;

$$MC = b\,x + c = 0.46849\,x + 18.8321, \text{ with } x \text{ in million acres}$$

$$(N = 13 \text{ (65 years)}, R^2 = 0.78, F(1, 11) = 38.24, t_b = 6.18, t_c = 4.21)$$

5/ The marginal investment cost for subsurface drainage systems appears to have generally decreased from 1870 to about 1910. It then increased until about 1965, but since has declined. The directly fitted equation for marginal cost from 16 first differences in investment and acreage from 1900-80 is:

$$MC = a\,x^2 + b\,x + c = -1.52117\,x^2 + 53.9846\,x - 68.2906, \text{ with } x \text{ in million acres drained}$$

$$(N = 16, R^2 = 0.83, F(2, 13) = 31.78, t_a = -3.25, t_b = 4.79, t_c = -1.23)$$

Table 19 --Average annual gross and net real capital investment in project onfarm conservation measures and improvements, and with Federal investment, United States, by 5-year periods 1936-80

Period	Gross annual conservation investment 1/				Net annual conservation investment 2/			
	All conservation	Conservation projects 3/	Onfarm measures 4/	Federal investment 5/	All investment	Conservation projects 3/	Onfarm measures 4/	Federal investment 5/
	-- Million dollars (1977) --							
1936-40	634	--	634	296	634	--	634	296
1941-45	1,366	--	1,366	639	1,280	--	1,280	598
1946-50	1,506	12	1,494	710	1,160	12	1,148	547
1951-55	981	20	961	469	241	18	223	120
1956-60	902	67	835	450	-138	64	-202	-39
1961-65	1,101	190	911	572	-57	170	-227	31
1966-70	842	202	640	503	-111	168	-279	-45
1971-75	645	200	445	348	-219	132	-351	-141
1976-80	623	176	447	290	-156	74	-230	-145

1/ Gross real investment in conservation is 20 percent of the sum for the period of annual conservation investments in current dollars, after each yearly amount was indexed (deflated) to 1977 price levels.
2/ Net real investment is gross real investment less depreciation allowances on existing gross capital stocks. Average depreciation for each component and period can be determined by subtracting net investment rates from corresponding gross rates. For example:

All depreciation, 1951-55: \$981 - \$241 = \$740 million/year (in 1977 dollars).

All depreciation, 1976-80: \$623-(-156) = \$623 + \$156 = \$779 million/year (in 1977 dollars).

3/ Includes capital investment for project-type works of improvement within formally organized watershed projects or by sponsoring organizations. Such investment includes any construction outlays plus the value of easements and rights-of-way, which is considered part of local contributions. This investment also covers direct Federal or other governmental construction expenditures for project improvements, whether made before or after formal watershed organizations were established.
4/ Includes all onfarm conservation improvements other than those structures and measures installed and cooperatively financed as project-type improvements. Temporary measures and recurring normal practices are not included, even though some capital investment may have been required.
5/ Rates of investment by farmers or local watershed organizations are the difference between rates for all conservation and Federal investment rates. Until 1943, the Federal investment includes only cost-sharing for onfarm conservation measures installed under USDA's Agricultural Conservation Program and since 1944, also covers Federal investments for works of improvements installed in the 11 Flood Prevention Watersheds projects administered by USDA. Since 1955, the Federal investment also includes Federal conservation investments made under the Watershed Protection and Flood Prevention Act of 1954, as amended. Since 1956 the Federal investment also accounts for cost-sharing assistance provided under the USDA's Great Plains Conservation Program.

SOURCES: See table 20.

Table 20 --Real gross capital stocks and net capital values for project and onfarm conservation measures and improvements, with federally financed shares, United States, 1940-80

Year	Gross capital stock, conservation 1/: All conservation	Gross capital stock, conservation 1/: Conservation projects 3/	Gross capital stock, conservation 1/: Onfarm measures 4/	Gross capital stock, conservation 1/: Federal share 5/	Net capital value, conservation 2/: All conservation	Net capital value, conservation 2/: Conservation projects	Net capital value, conservation 2/: Onfarm measures	Net capital value, conservation 2/: Federal share
	Billion dols. (1977)	--- Percent 6/ ---			Billion dols. (1977)	--- Percent 6/ ---		
1940	3.172	--	100.0	46.8	3.172	--	100.0	46.8
1945	10.001	--	100.0	46.8	9.574	--	100.0	46.8
1950	17.533	0.3	99.6	46.9	15.375	0.4	99.6	46.9
1955	22.437	.7	99.3	47.1	16.581	.9	99.1	47.9
1960	26.945	1.8	98.2	47.5	15.890	3.0	97.0	48.0
1965	29.034	5.0	95.0	48.8	15.603	8.7	91.3	49.6
1970	26.659	9.2	90.8	50.6	15.046	14.7	85.3	49.9
1975	22.411	15.4	84.6	52.4	13.952	20.5	79.5	48.8
1980	20.722	20.9	79.1	52.8	13.170	24.6	75.4	46.2

1/ Gross capital stocks for conservation are the sum of conservation investments since 1936 indexed to 1977 dollars, less all those measures considered to be fully depreciated. Measures only partly depreciated are included in the gross stock at their full cost in 1977 dollars.
2/ Net capital values are the sum of investments since 1936 less all accured depreciation. Net capital values are less than gross capital stocks by the amount by which just those measures still in use had depreciated as of the year indicated.
3/, 4, 5/ See table 19.
6/ Percentages for conservation projects and onfarm measures add to 100. The Federal shares is a separate percentage and after 1944 involves participation in conservation projects as well as onfarm cost-sharing assistance.

SOURCES: U.S. Department of Agriculture agencies:

Agricultural Stabilization and Conservation Service: Participation and cost-sharing information since 1936 on the Agricultural Conservation Program for permanent onfarm conservation measures, as reported in "Agricultural Statistics" (annual) or in other agency reports and statistical summaries.

Soil Conservation Service: Participation and cost-sharing information since 1957 on the Great Plains Conservation Program for permanent onfarm conservation measures as reported in "Agricultural Statistics" (annual) or otherwise supplied. Also Federal and non-Federal expenditures for project measures installed since 1946 in authorized Flood Prevention Watersheds and since 1957 in watersheds improved under the Watershed Protection and Flood Prevention Act (Public Law 83-566).

Table 21 -- Summary of average service lives assumed for depreciation purposes

On-Farm Irrigation Improvements and Equipment 1/	Service life (years)
Irrigation land leveling	20
Land smoothing	10
Permanent open ditches	20
Gravity irrigation systems (average)	20
Wells and stream improvements	25
Electric motors	20
Diesel, natural gas, propane engines	15
Gasoline engines	9
Centrifugal and turbine pumps	20
Irrigation tubing and pipes (variable with materials)	5-40
Complete sprinkler irrigation systems (variable with type)	10-20
Federal ACP or Great Plains program irrigation cost-shares	20
Project Irrigation Facilities	
Bureau of Reclamation projects	2/
Non-federal projects: If built before 1900	20
If built 1901-20	30
If built 1921-50	50
If built after 1950	75
On-Farm Drainage Improvements	
Leveling and smoothing (same as irrigation)	20, 10
Field ditches	10
Lateral ditches	20
Main outlets	30
Surface drainage systems (average)	20
Subsurface drains: tile, etc., installed before 1940	30
Tile, etc., installed 1940 or later	40
Federal ACP program drainage cost-shares	30
Project Drainage Facilities 3/	60
On-Farm Conservation Measures 4/	25
PL 566 and Flood Prevention Watershed Improvements	
Water supply structures	50
Other permanent improvements and measures 4/	30

1/ For more information on the depreciation and the estimated service life of numerous components of irrigation systems see the chapter "Economics of Sprinkler Irrigation" in the handbook Sprinkler Irrigation (eds. Claude H. Pair and others), 3rd ed. Sprinkler Irrigation Association, Washington, D.C. 1969, 444 pp. See also the chapter "Farm Resources and System Selection" by G. T. Thompson, L. B. Spiess and J. H. Krider in the new ASAE Monograph 3 on Design and Operation of Farm Irrigation Systems (Marvin Jensen, ed.), American Society of Agricultural Engineers, St. Joseph, Mich., December 1980, 829 pp.

2/ Indefinite life assumed. Depreciation allowance taken as annual expenditures since 1949 for rehabilitation and betterment of older projects.

3/ Maintained public drains over 60 years old are assumed to retain 50 percent of their original real cost indefinitely.

4/ Applies to farmer and local investments as well as Federal cost sharing or other contributions. Assuming recommended maintenance, depreciation is deferred 5 years beyond year of installation.

Figure 1

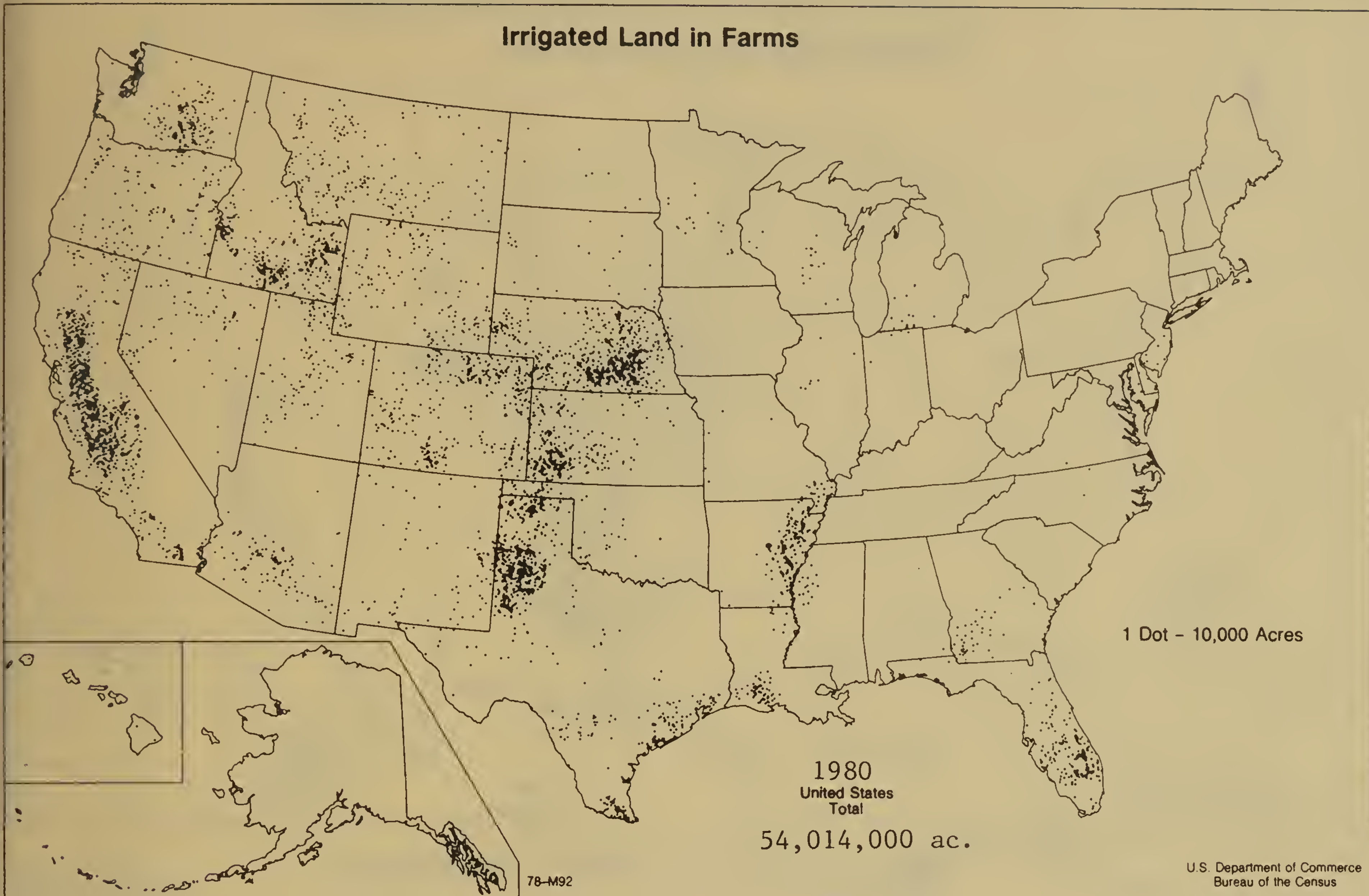

Irrigated Land in Farms
1 Dot - 10,000 Acres
1980
United States
Total
54,014,000 ac.
78-M92
U.S. Department of Commerce
Bureau of the Census

Figure 2

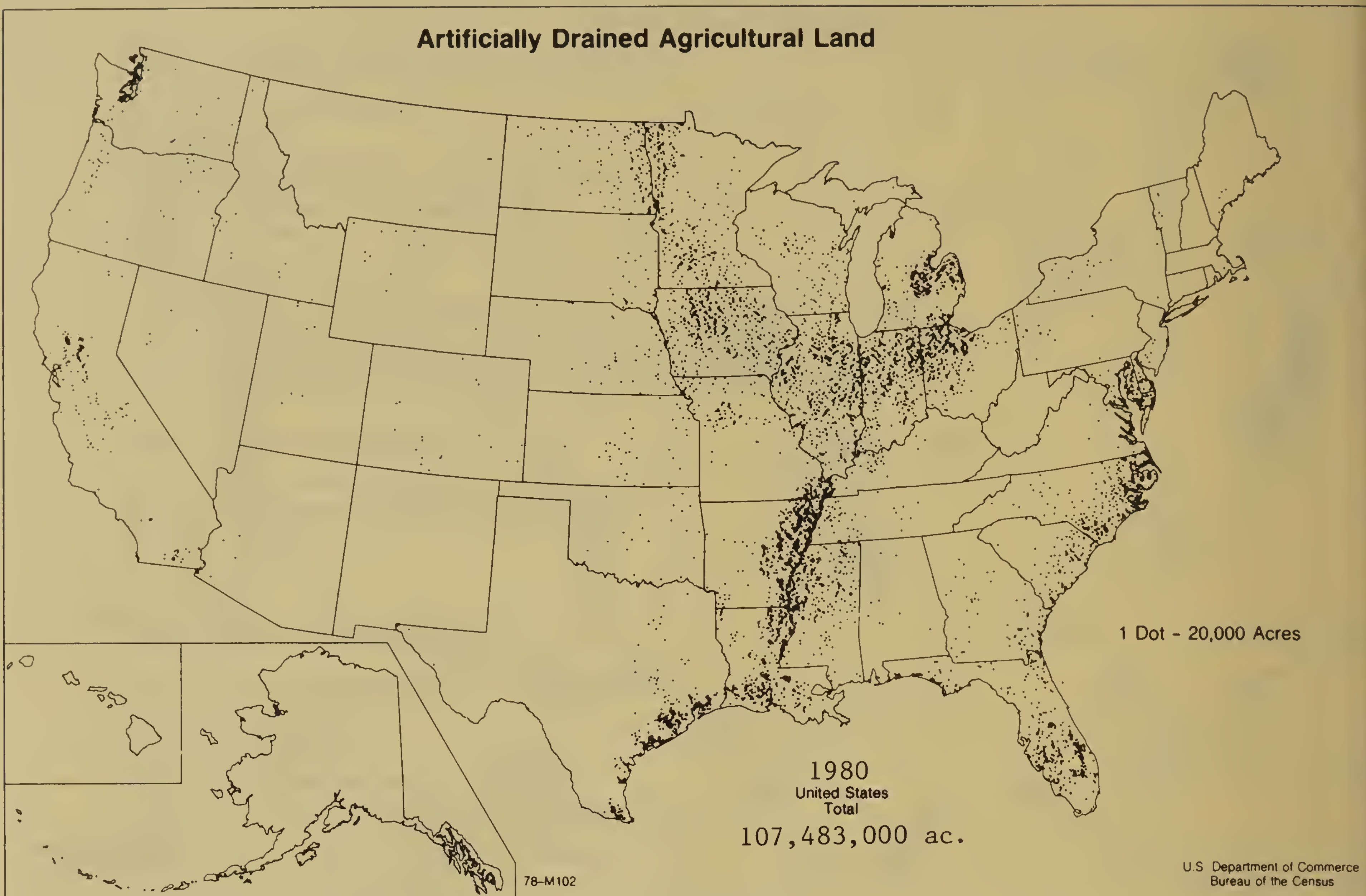
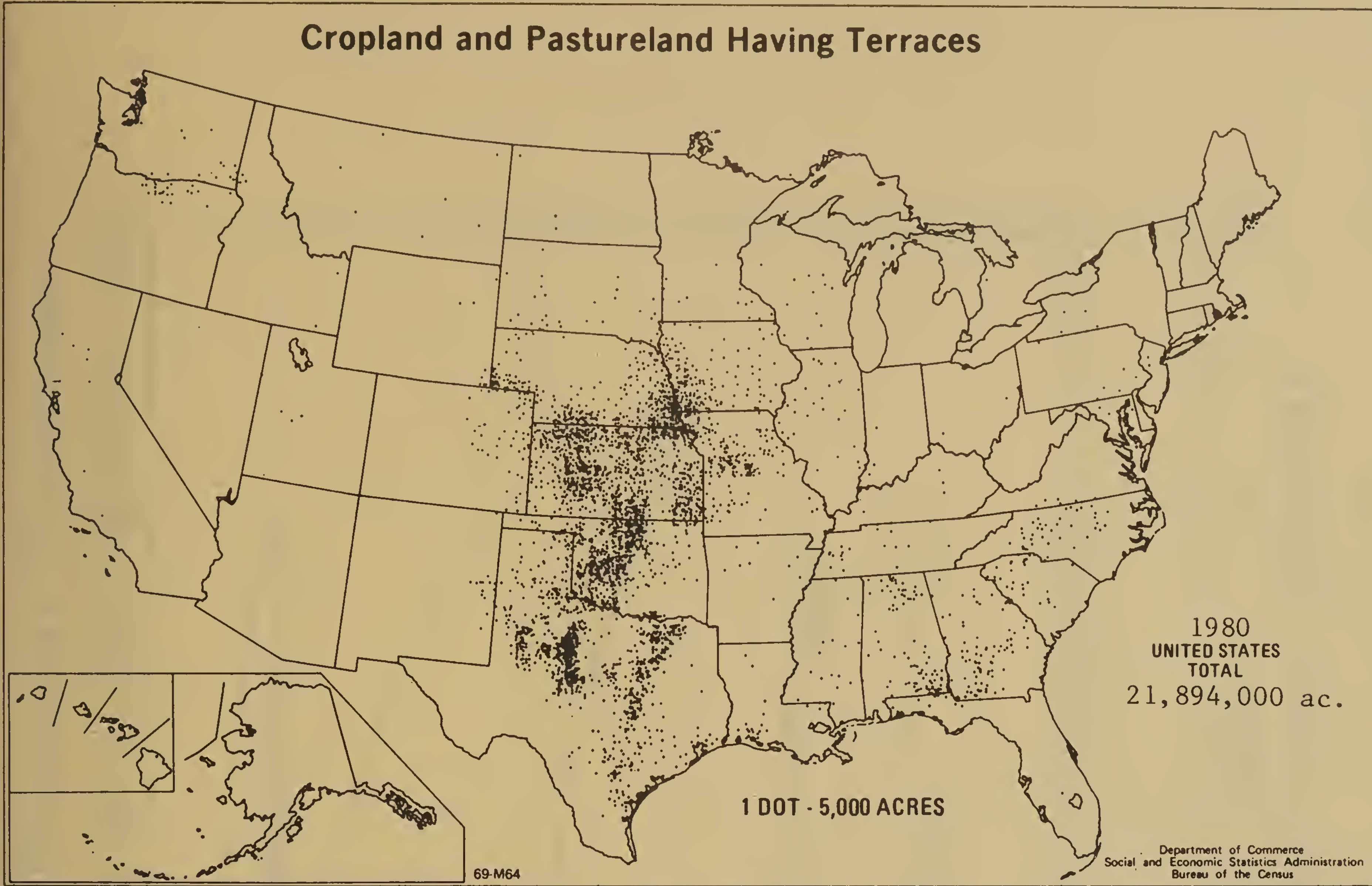
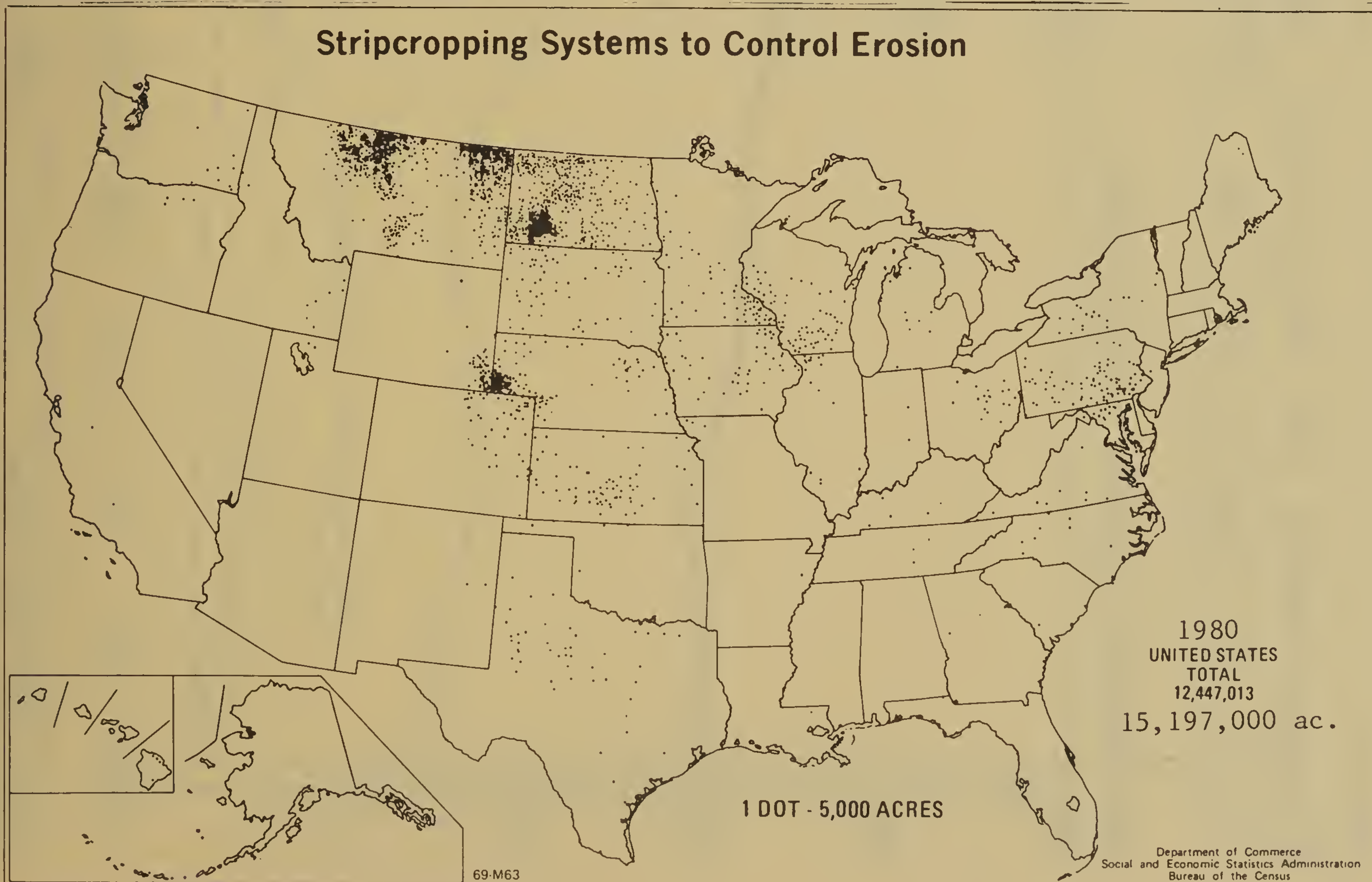

Artificially Drained Agricultural Land
1 Dot - 20,000 Acres
1980
United States
Total
107,483,000 ac.
78-M102
U.S. Department of Commerce
Bureau of the Census

Figure 3



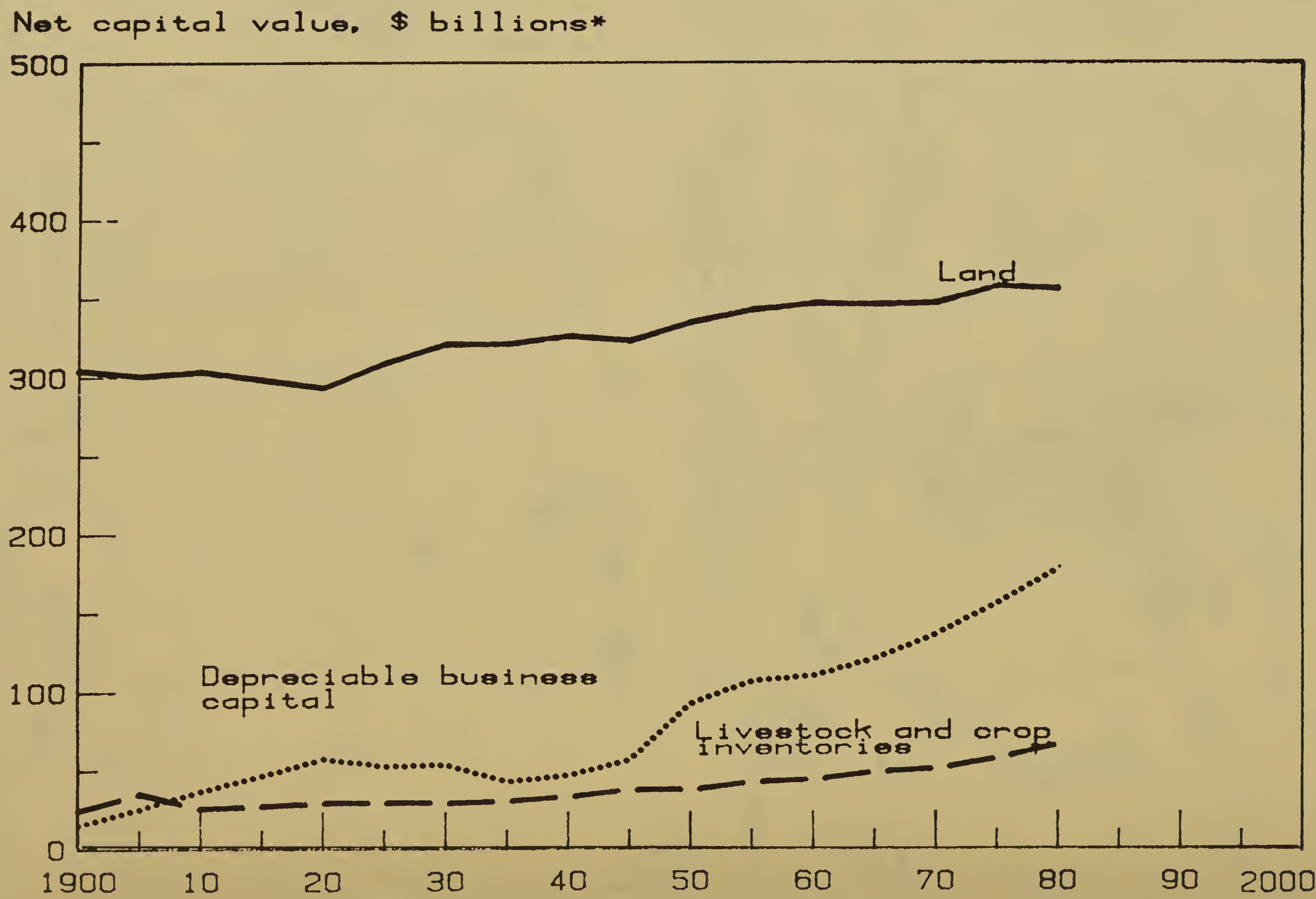
Cropland and Pastureland Having Terraces
1980
UNITED STATES
TOTAL
21,894,000 ac.
1 DOT - 5,000 ACRES
69-M64
Department of Commerce
Social and Economic Statistics Administration
Bureau of the Census



Stripcropping Systems to Control Erosion
1980
UNITED STATES
TOTAL
12,447,013
15,197,000 ac.
1 DOT - 5,000 ACRES
69-M63
Department of Commerce
Social and Economic Statistics Administration
Bureau of the Census

Figure 4

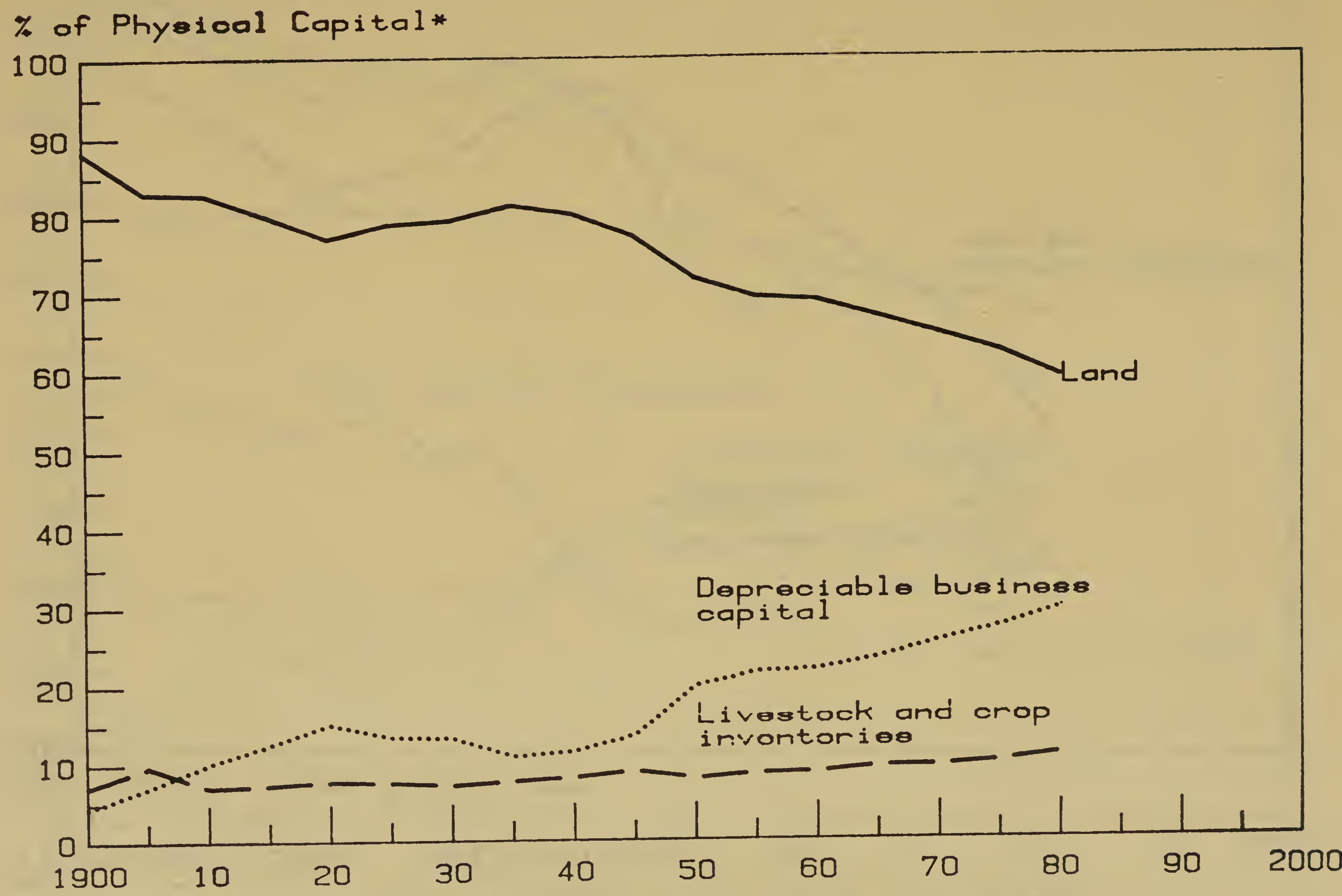
Components Of Physical Business Capital In U.S. Agriculture, 1900-1980



* In 1977 dollars.

Figure 5

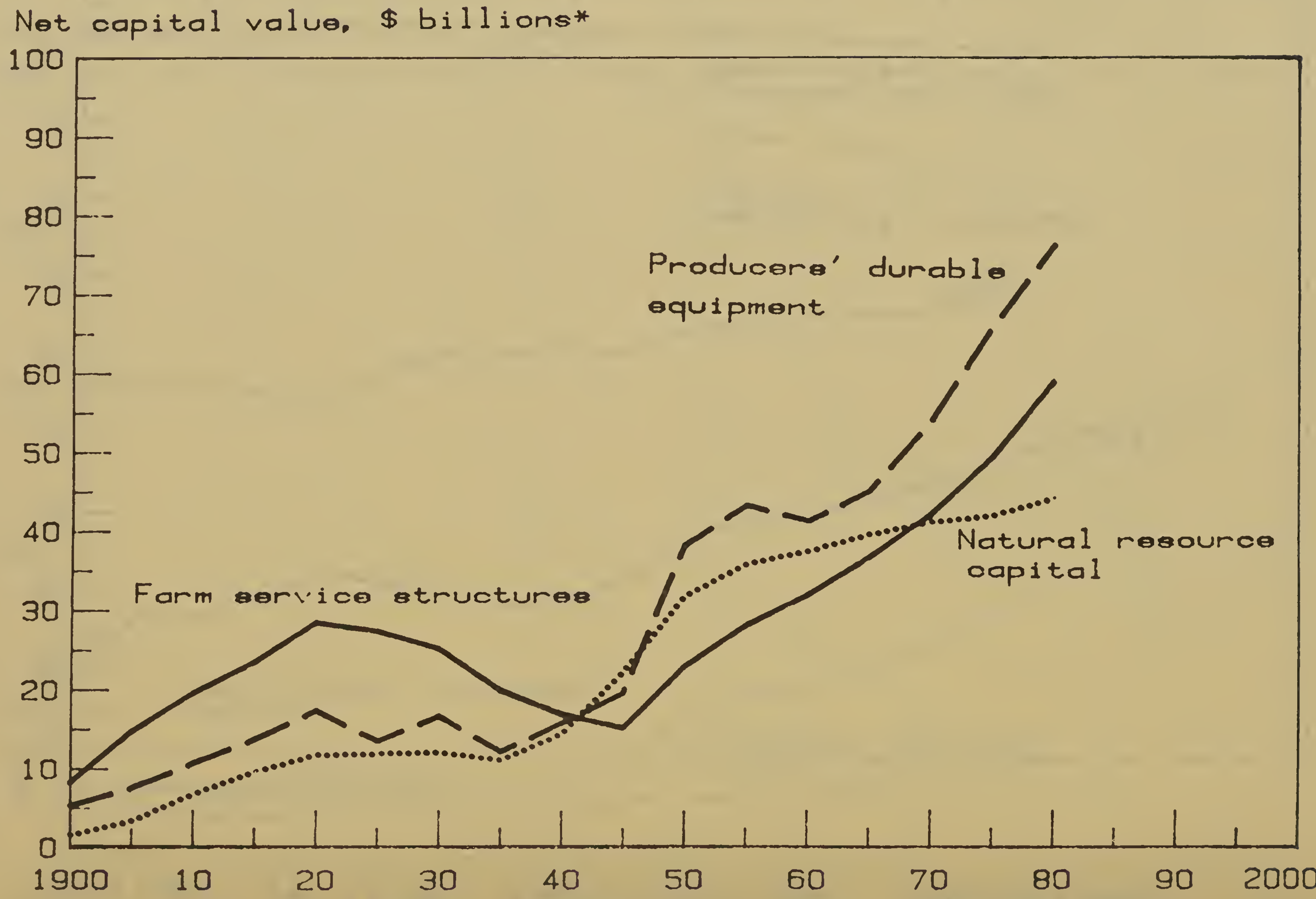
Changing Composition Of Physical Business Capital In U.S. Agriculture, 1900-1980



* Physical business capital in constant (1977) dollars.

Figure 6

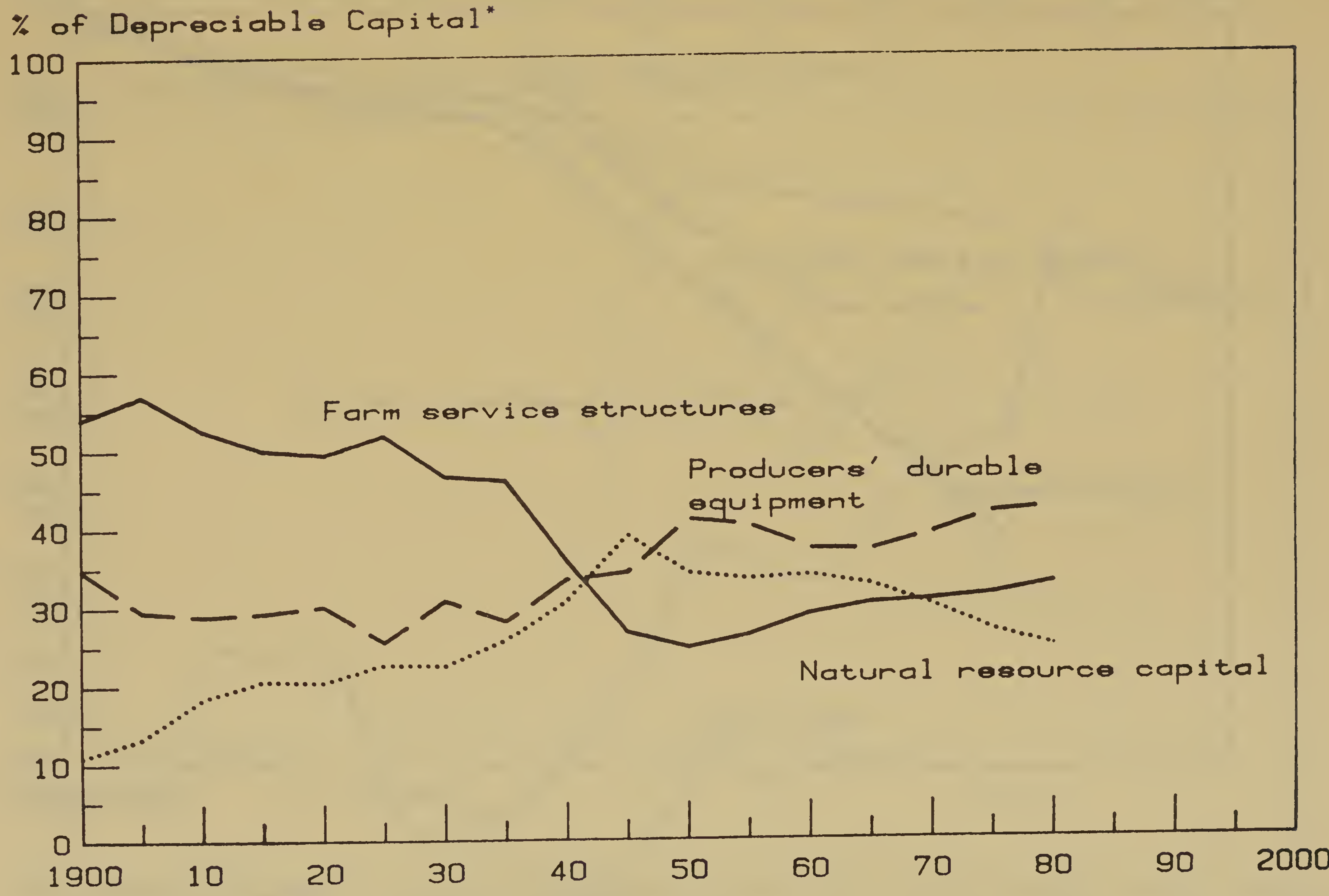
Depreciable Business Capital In U.S. Agriculture, 1900-1980



* In 1977 dollars; net value=total investment to date less depreciation to data.

Figure 7

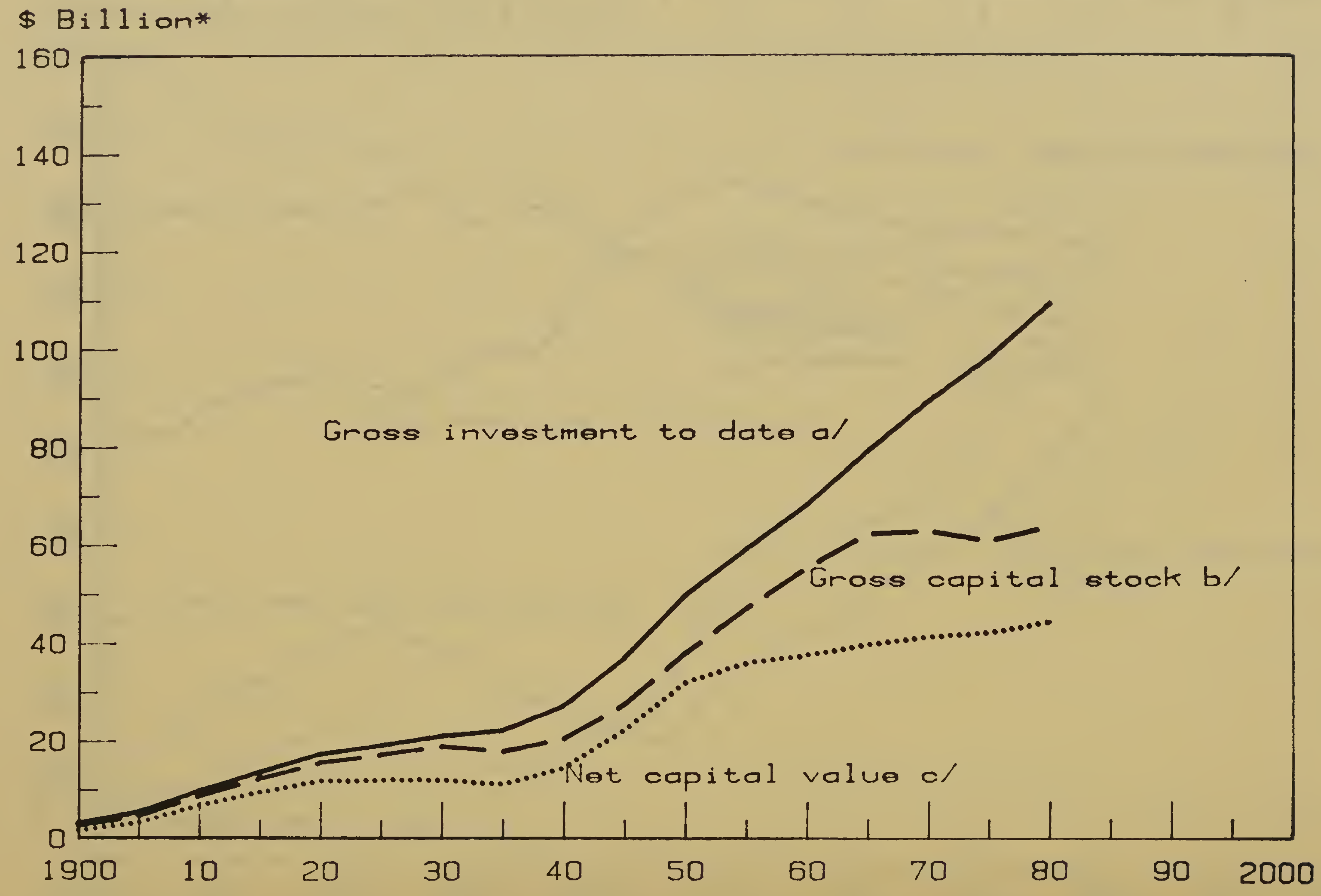
Changing Composition Of Depreciable Business Capital In U.S. Agriculture, 1900-1980



* Depreciable capital in constant (1977) dollars.

Figure 8

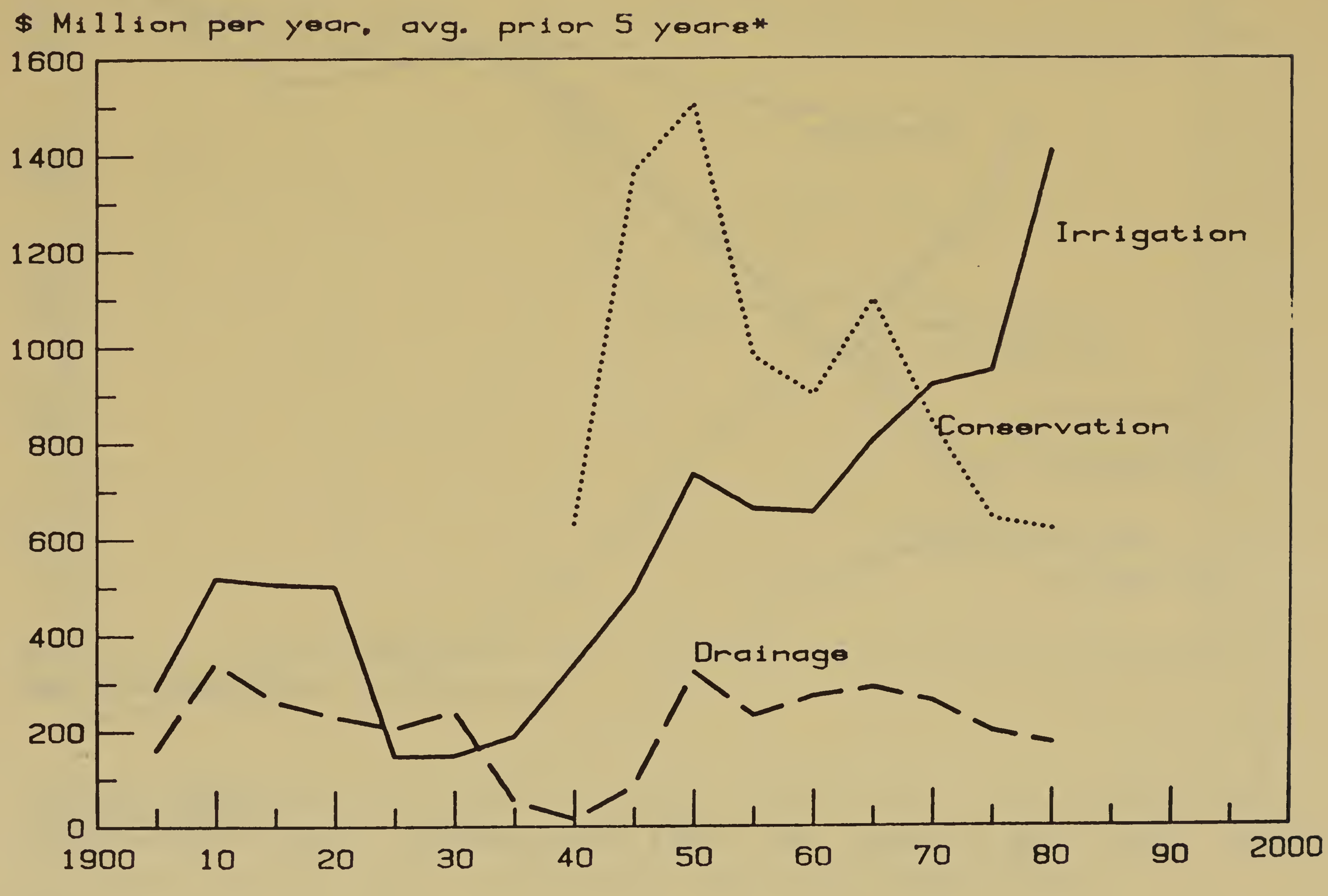
Natural Resource Capital Formation In U.S. Agriculture, 1900-1980



* In 1977 dollars. a/ Cumulative gorss investment in 1977 dollars. b/ Full-cost value of facilities still in use. c/ Net value = depreciated value of facilities still in use, or gross investment to date less depreciation to date.

Figure 9

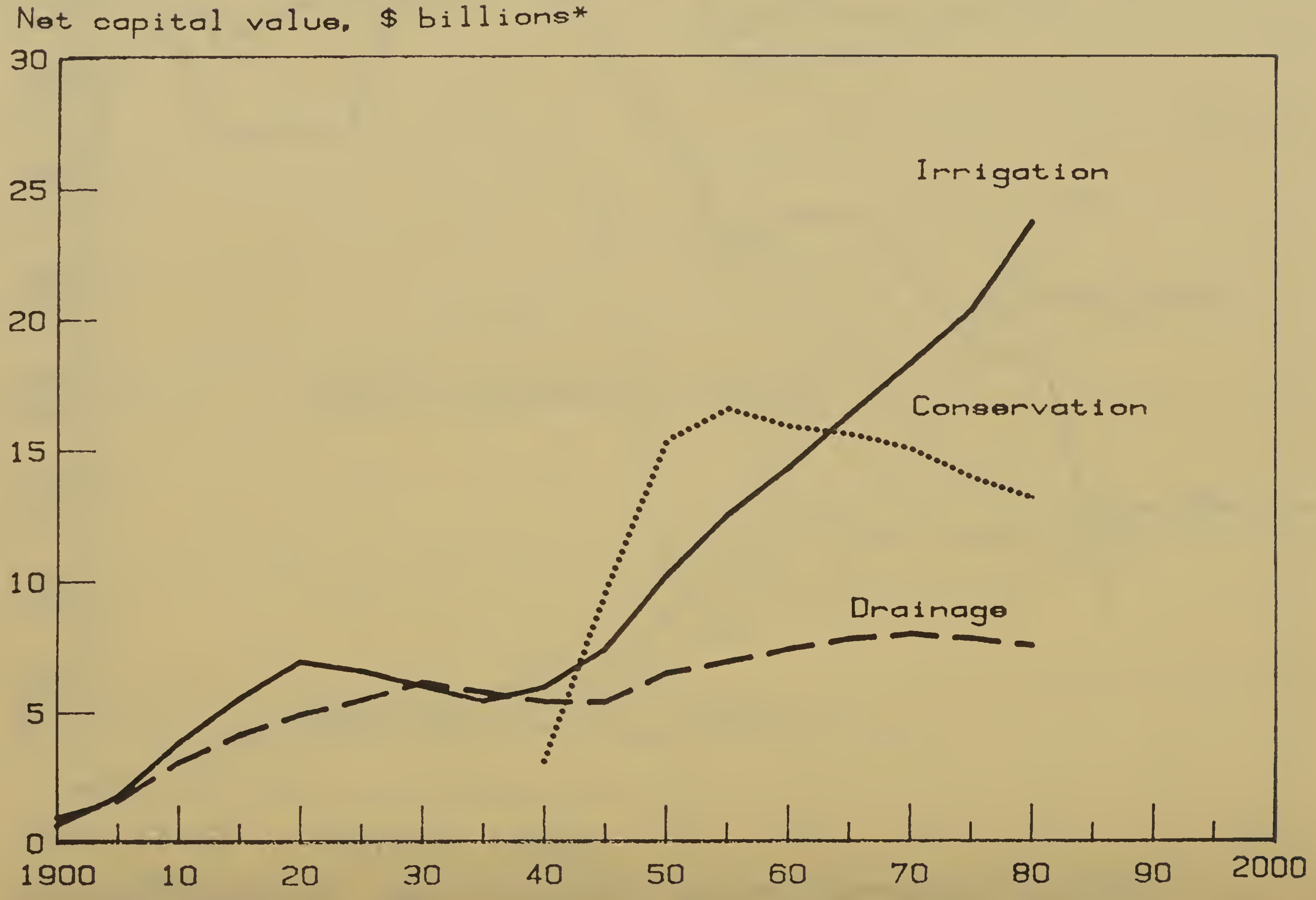
Comparative Rates of Gross Investment For Irrigation, Drainage And Conservation in The U.S., 1900-1980



* In 1977 dollars.

Figure 10

Comparative Net Capital in Irrigation, Drainage and Conservation In The U.S., 1900-1980



* In 1977 dollars; net value = total investment to date less depreciation to date.

Figure 11

Land Irrigated In The U.S.: With and Without Project Facilities, 1900-1980

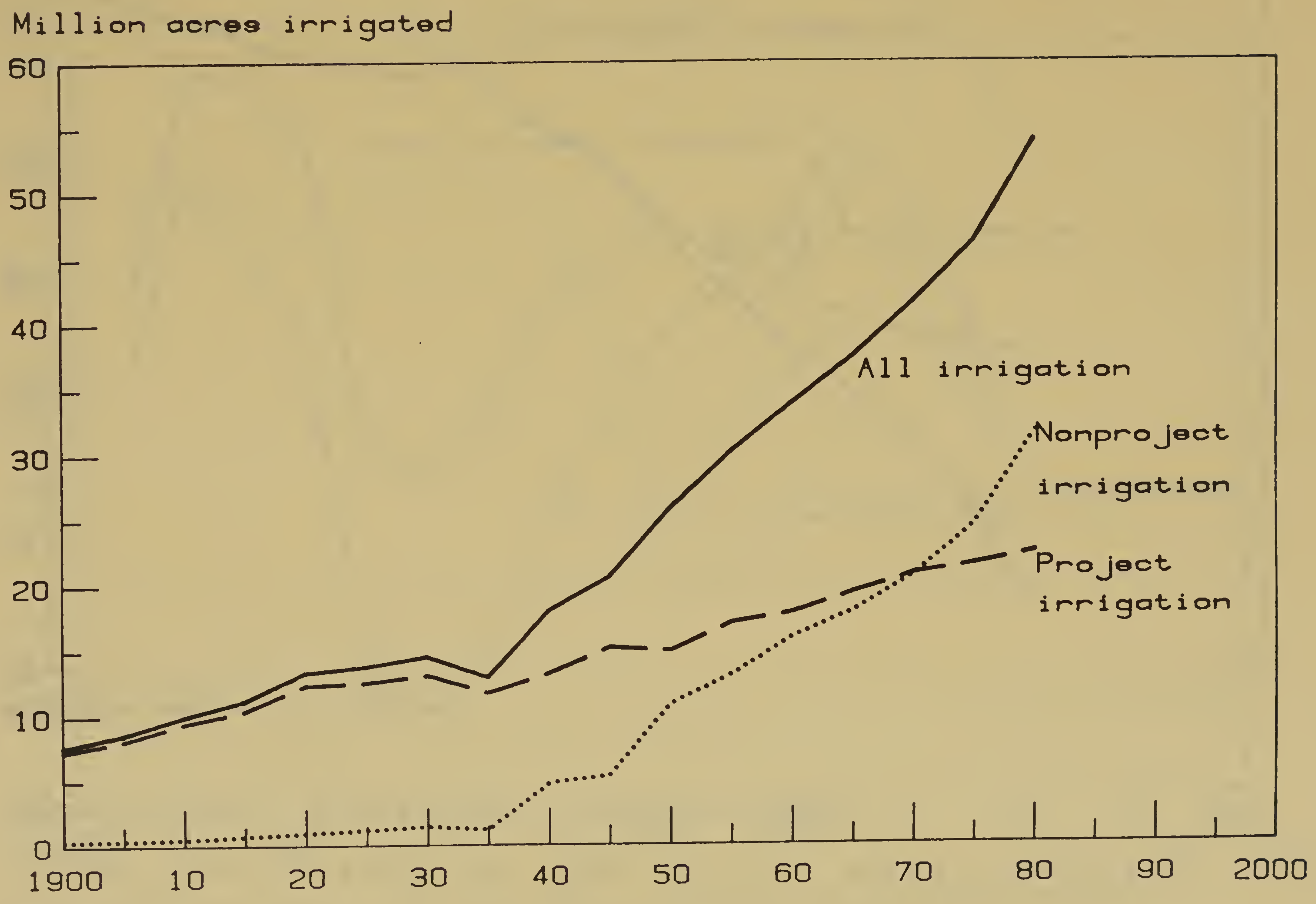


Figure 12

Land Irrigated In The U.S.: With Gravity and Sprinkler Systems, 1900-1980

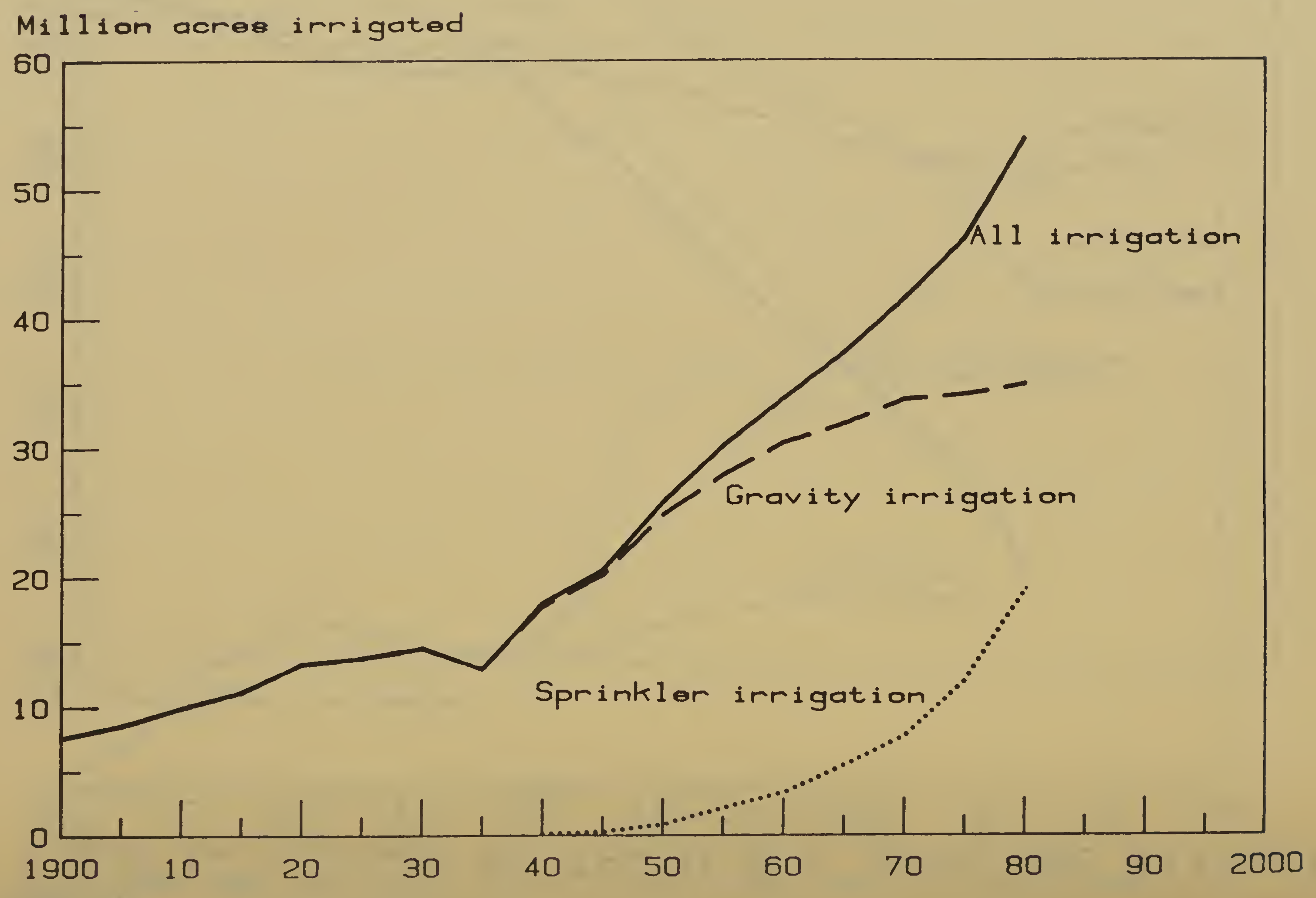
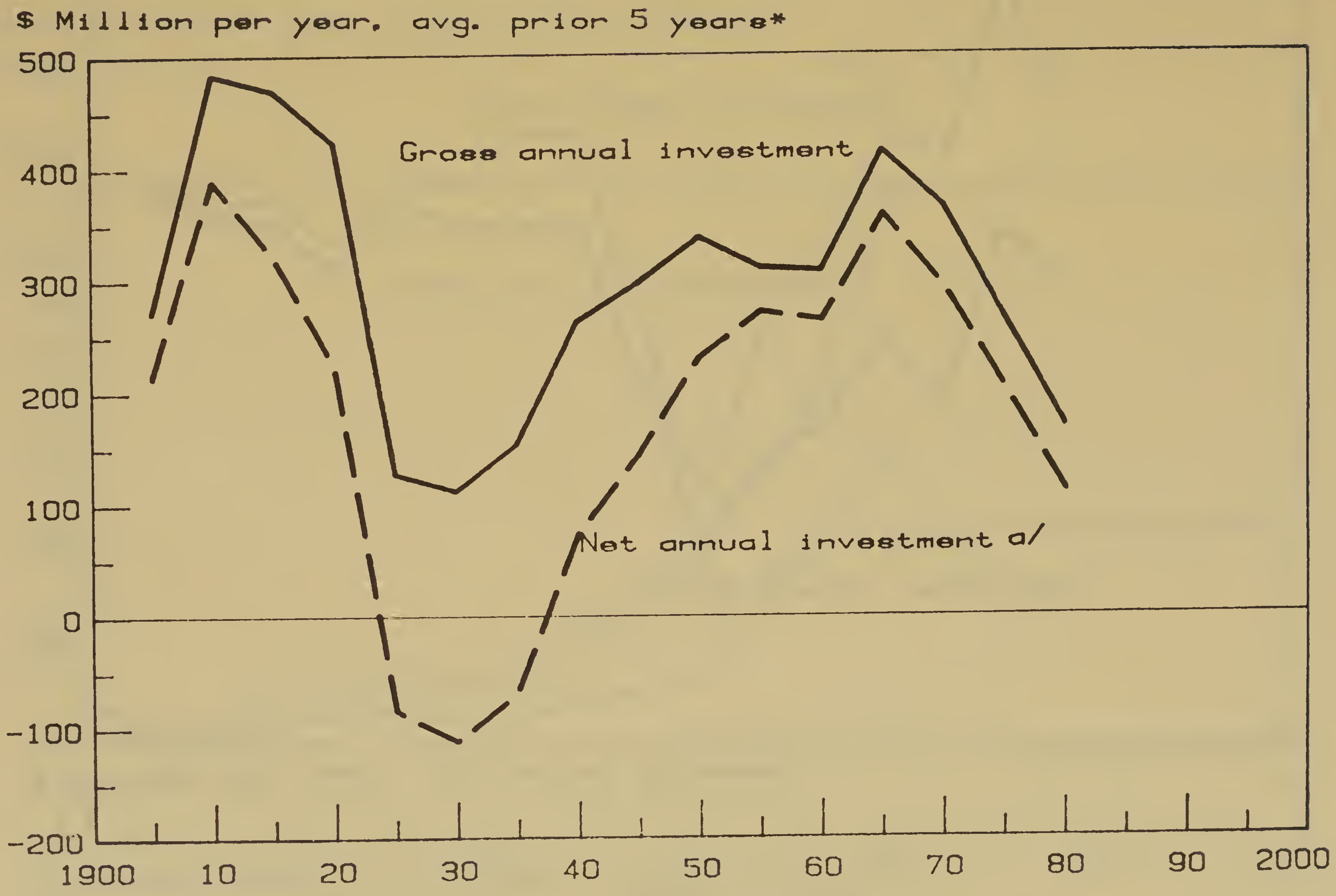


Figure 13

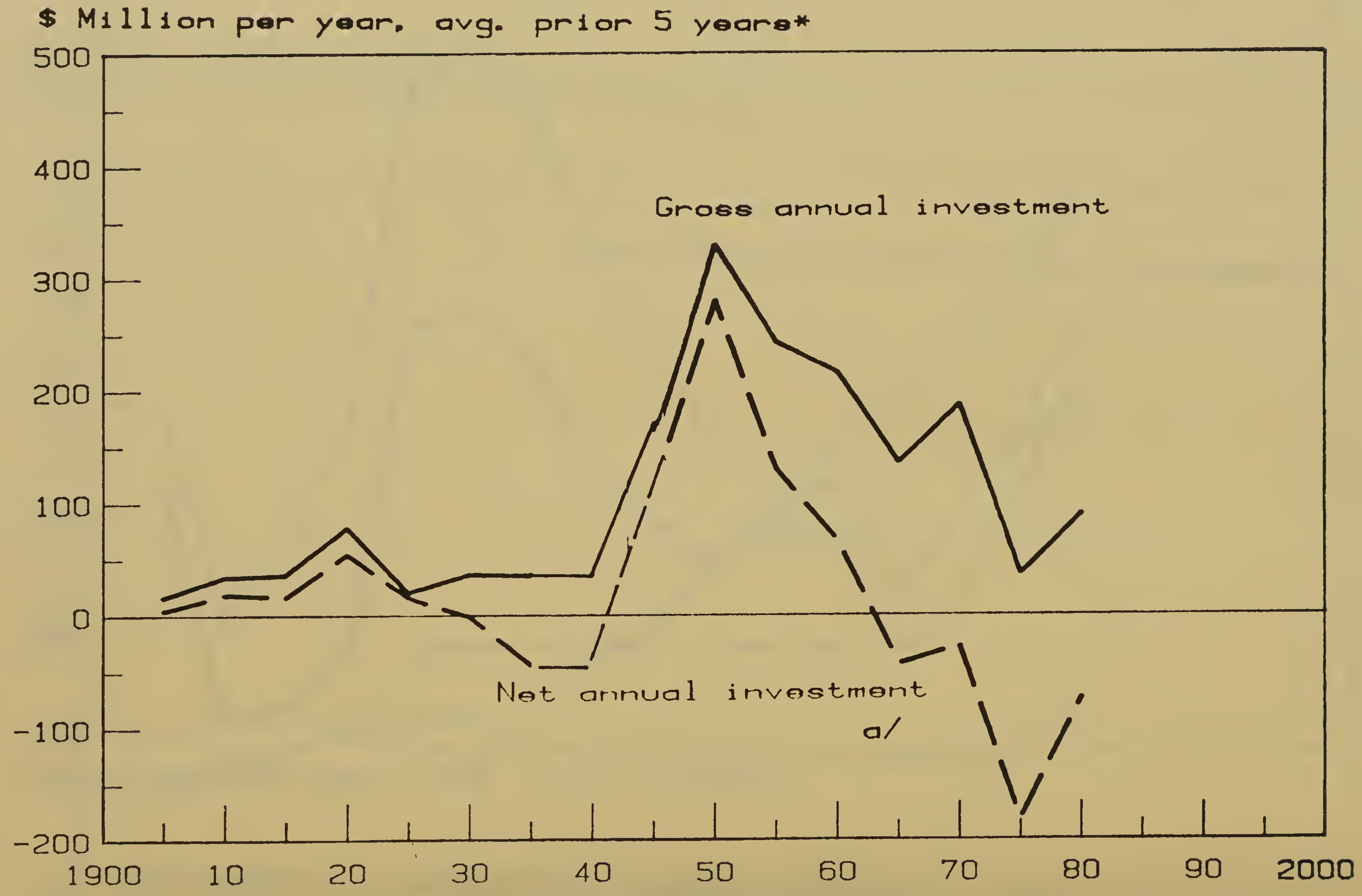
Project Irrigation In The U.S.: Annual Investment Trends, 1900-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 14

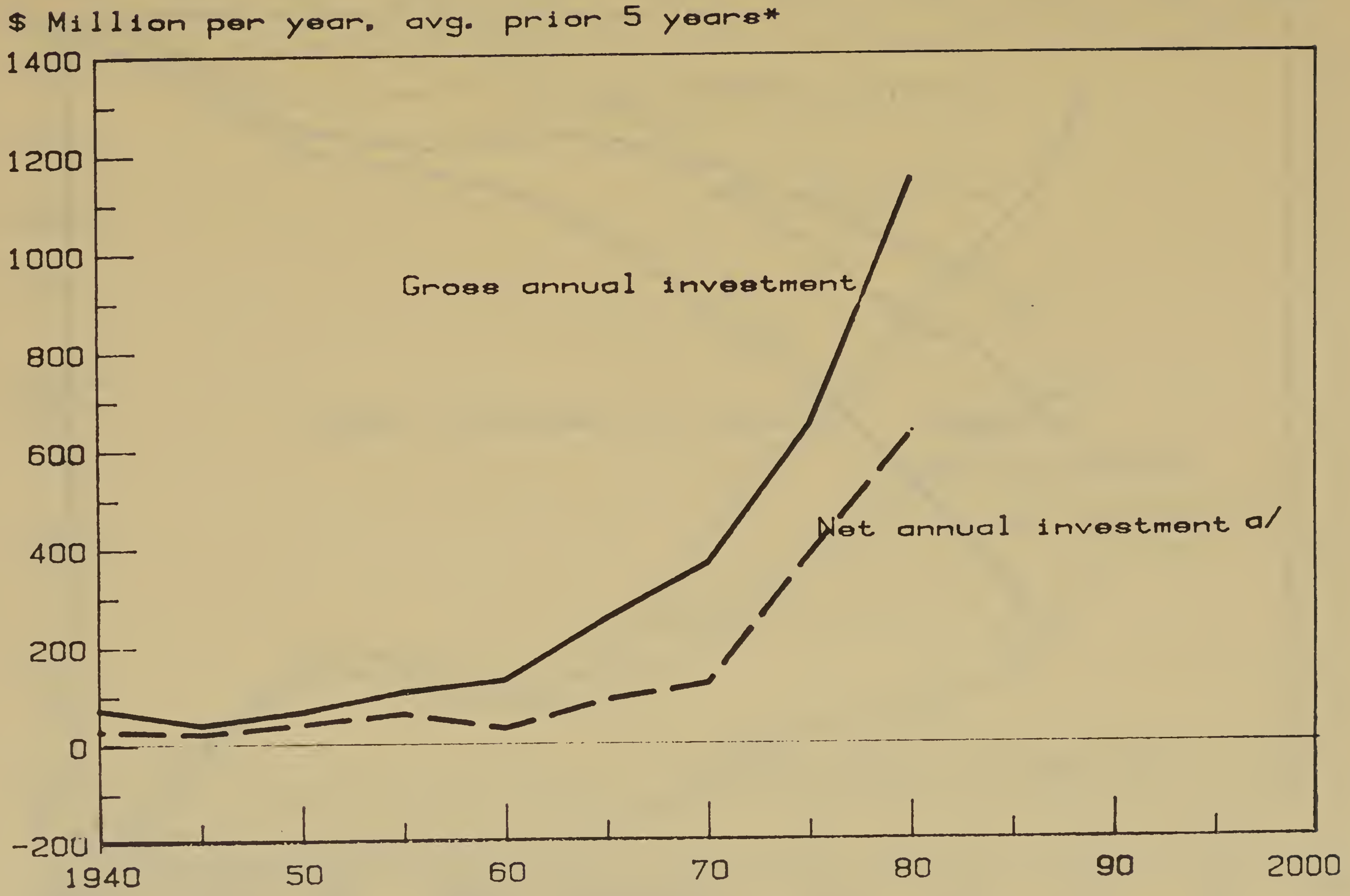
Gravity Irrigation On U.S. Farms: Annual Investment Trends, 1900-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 15

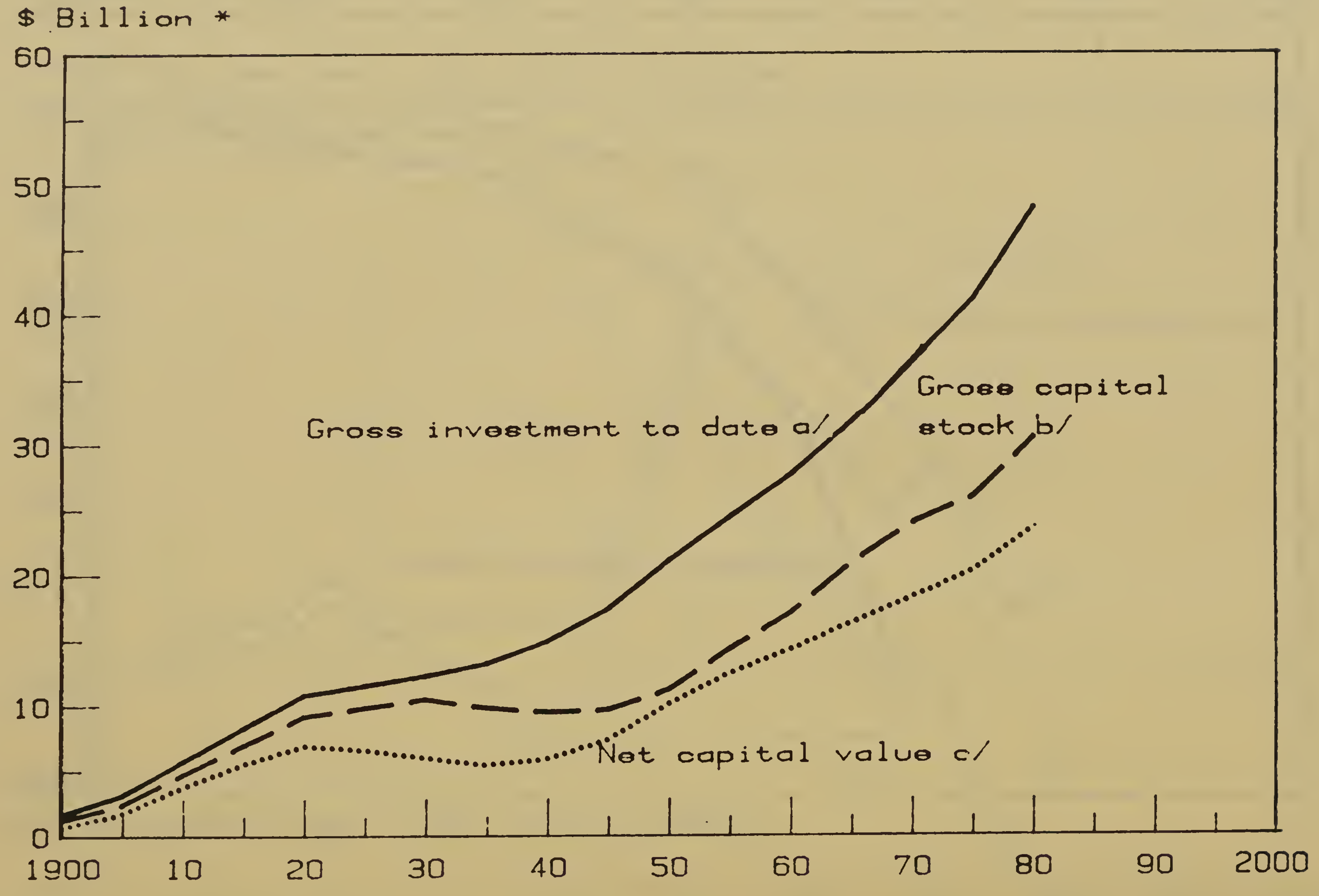
Sprinkler Irrigation On U.S. Farms: Annual Investment Trends, 1940-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 16

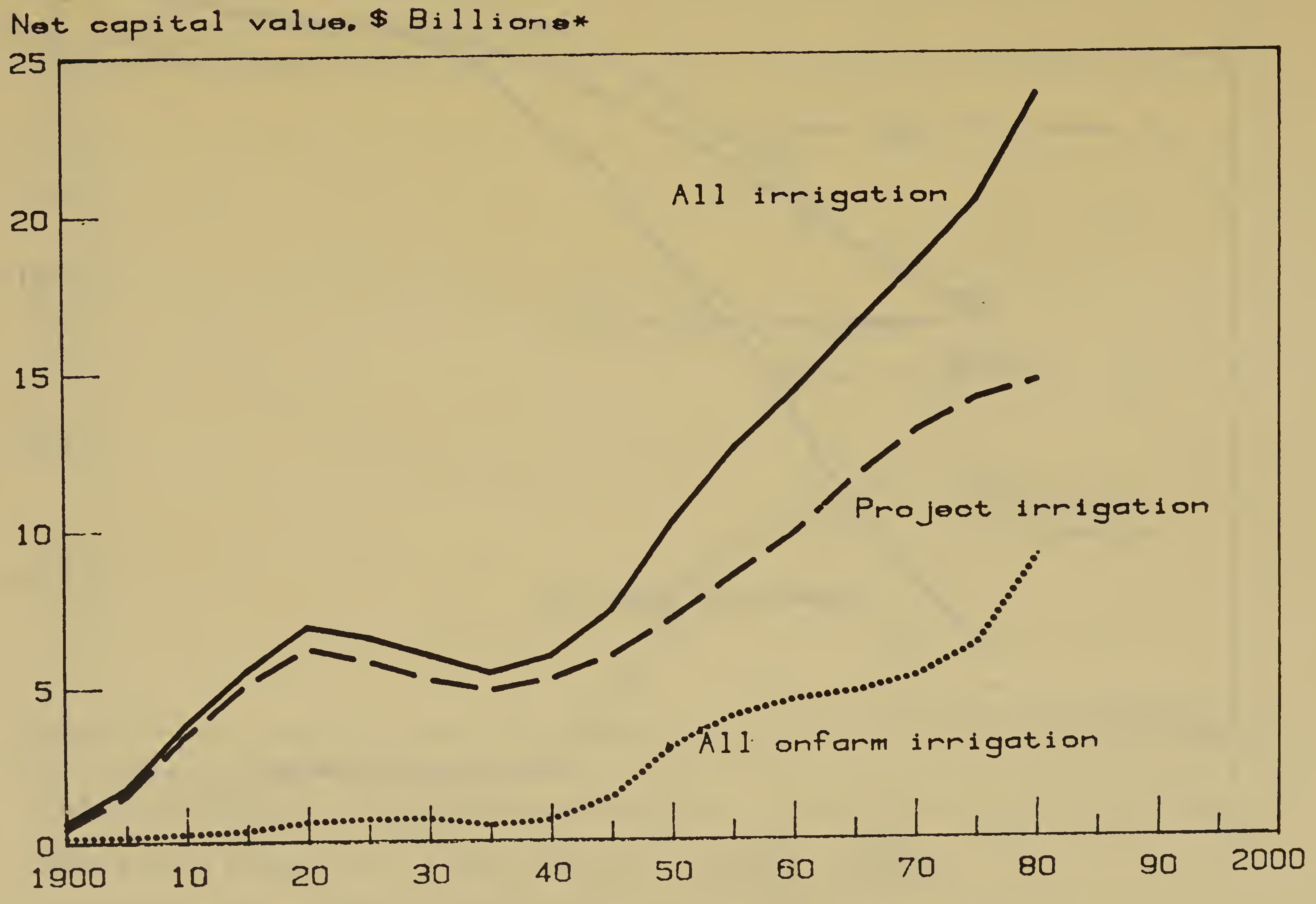
Irrigation Capital Formation in U.S. Agriculture, 1900-1980



* In 1977 dollars. a/ Cumulative gross investment in 1977 dollars. b/ Full-cost value of facilities still in use. c/ Net value = depreciated value of facilities still in use, or gross investment to date less depreciation to date.

Figure 17

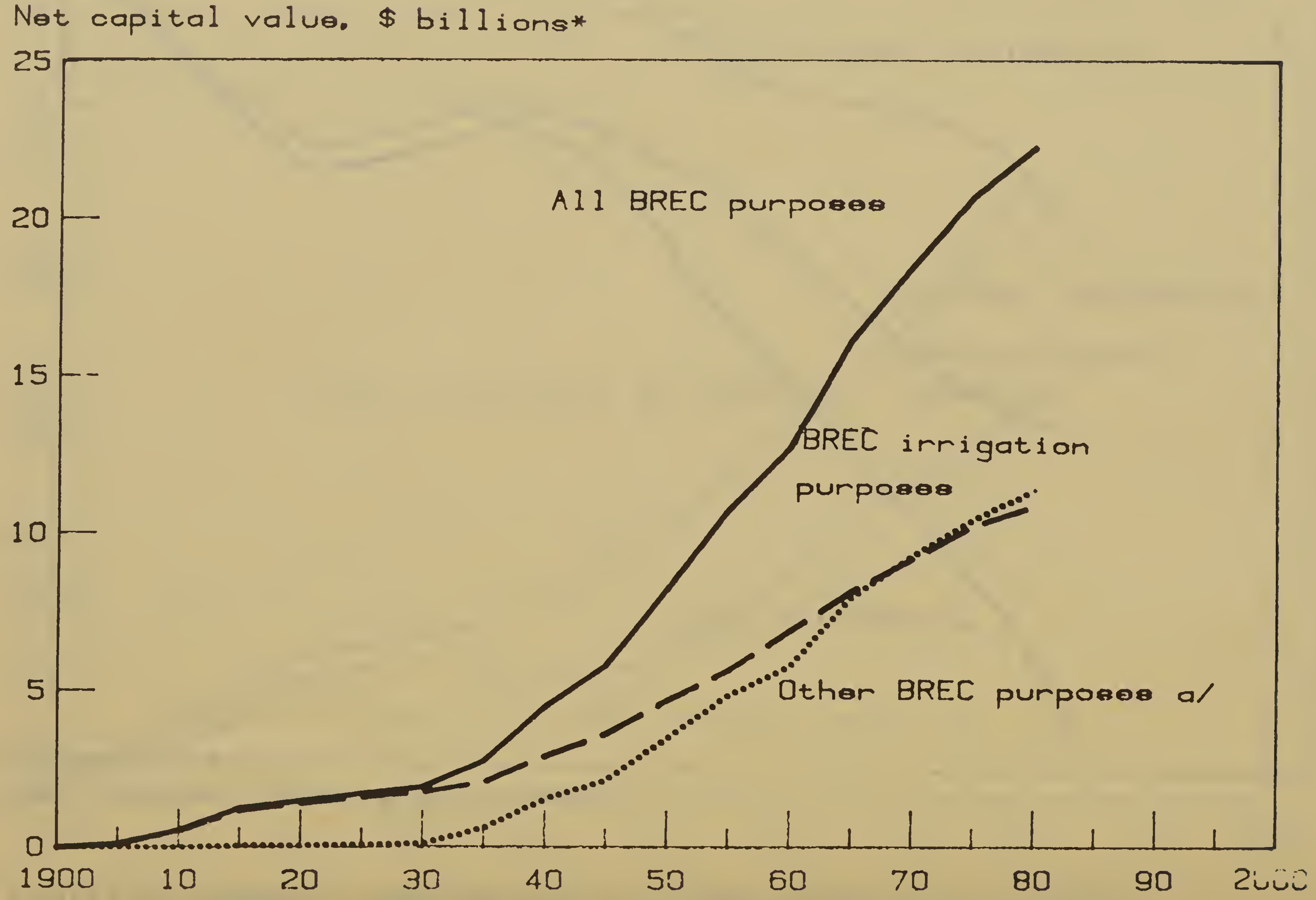
Irrigation Capital In The U.S.: Project And Onfarm Capital Values, 1900-1980



* In 1977 dollars; net value=total investment to date less depreciation to data.

Figure 18

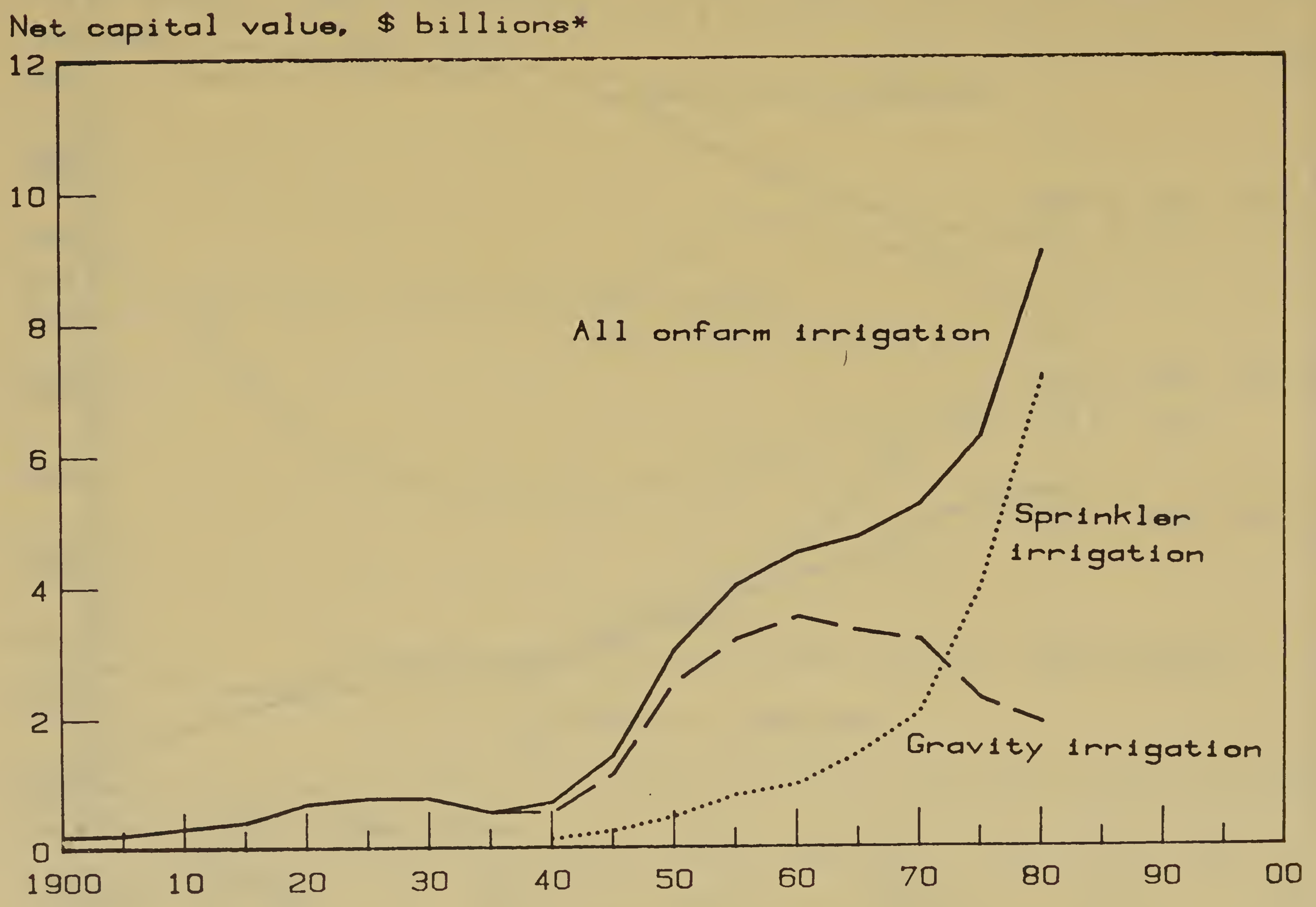
Bureau Of Reclamation Irrigation and Nonirrigation Capital, 1900-1980



* In 1977 dollars; net value = total investment to date less depreciation to data. a/ Including hydropower, navigation, flood control, water supply, recreation, etc.

Figure 19

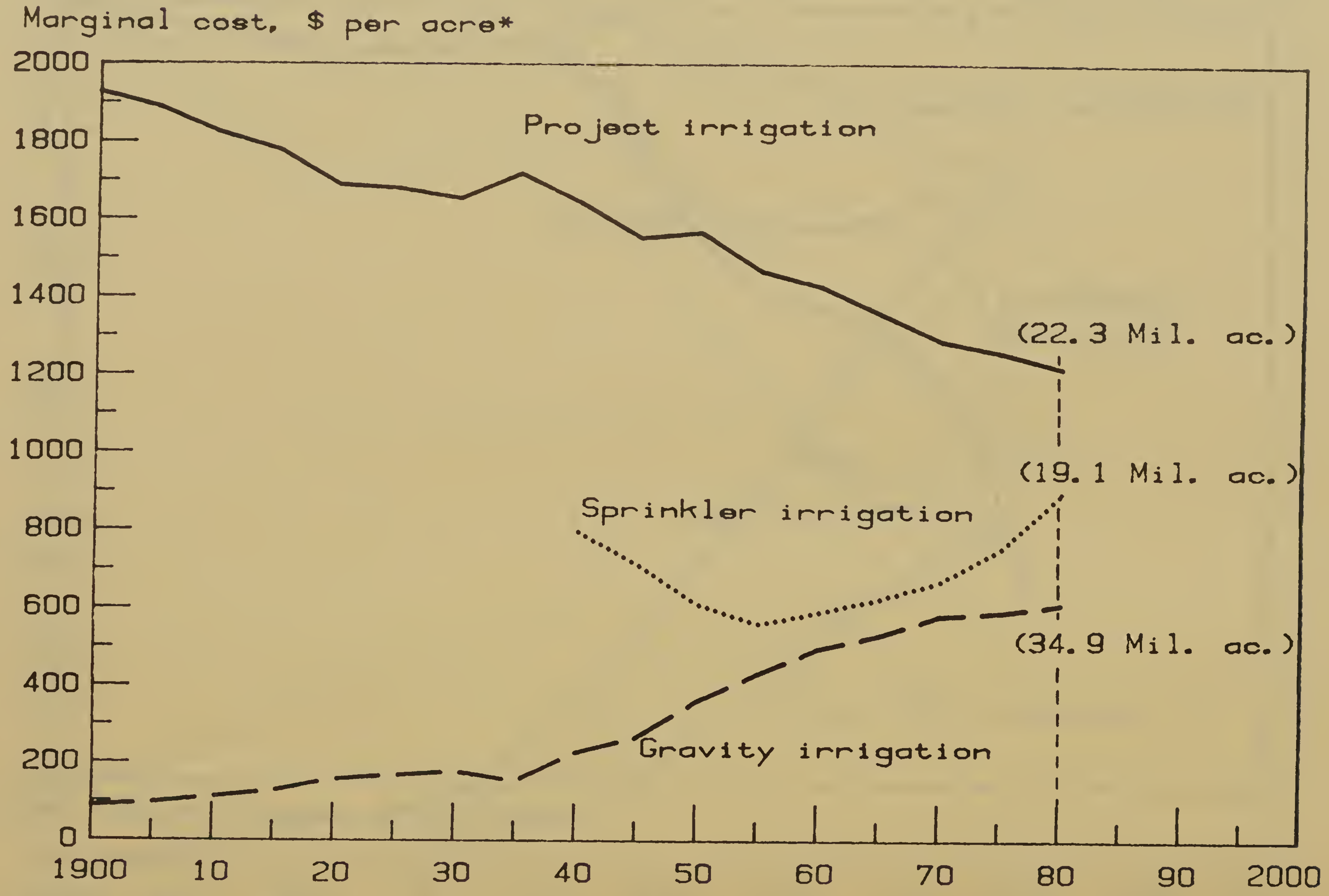
Onfarm Gravity And Sprinkler Irrigation Capital In The U.S., 1900-1980



* In 1977 dollars: net value=total investment to date less depreciation to date.

Figure 20

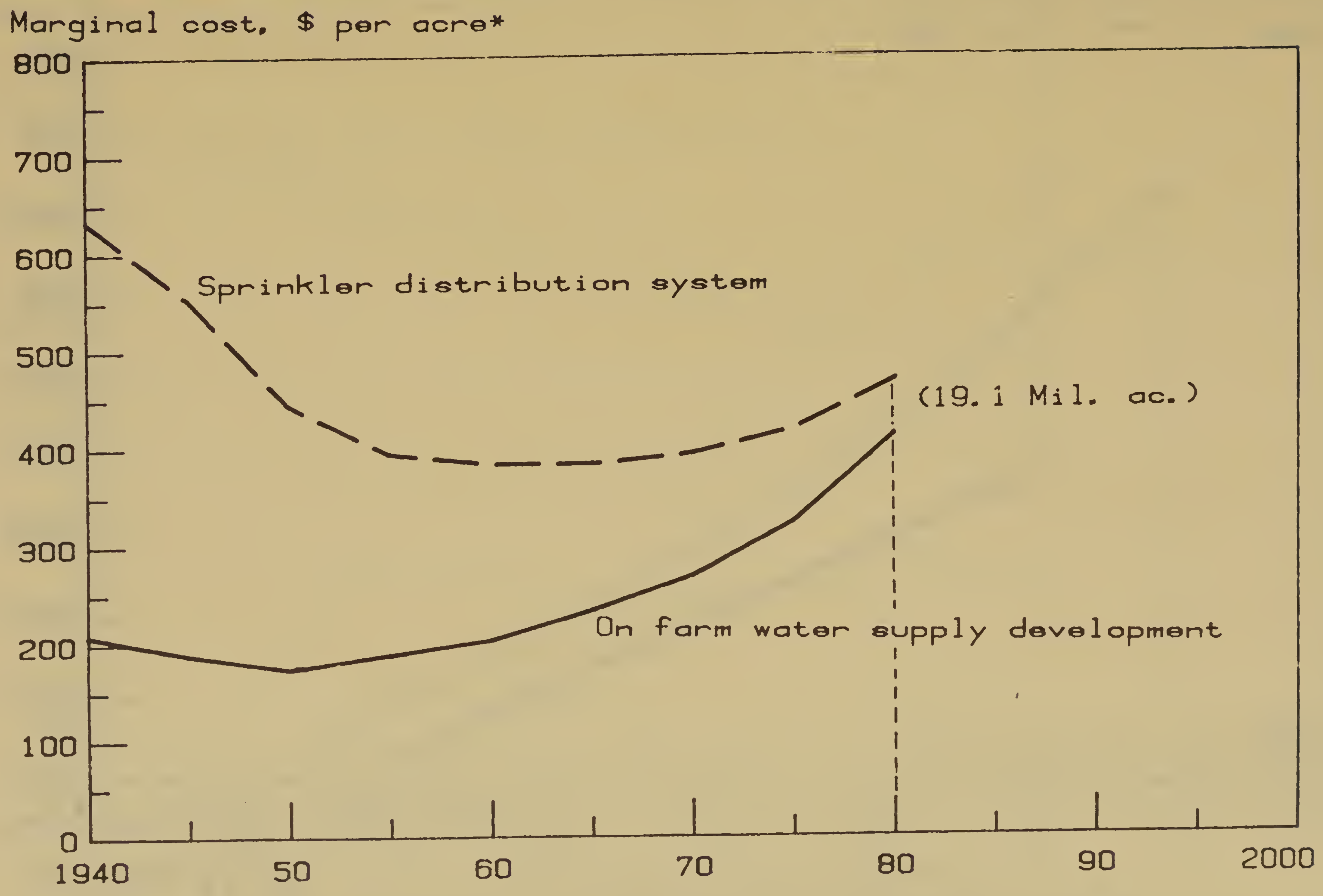
Changing Marginal Costs Of Irrigation In The U.S.: Project, Gravity and Sprinkler Costs, 1900-1980



* In constant (1977) dollars. Marginal cost is the added investment required to expand irrigation by 1 acre from the acreage irrigated as of any year shown.

Figure 21

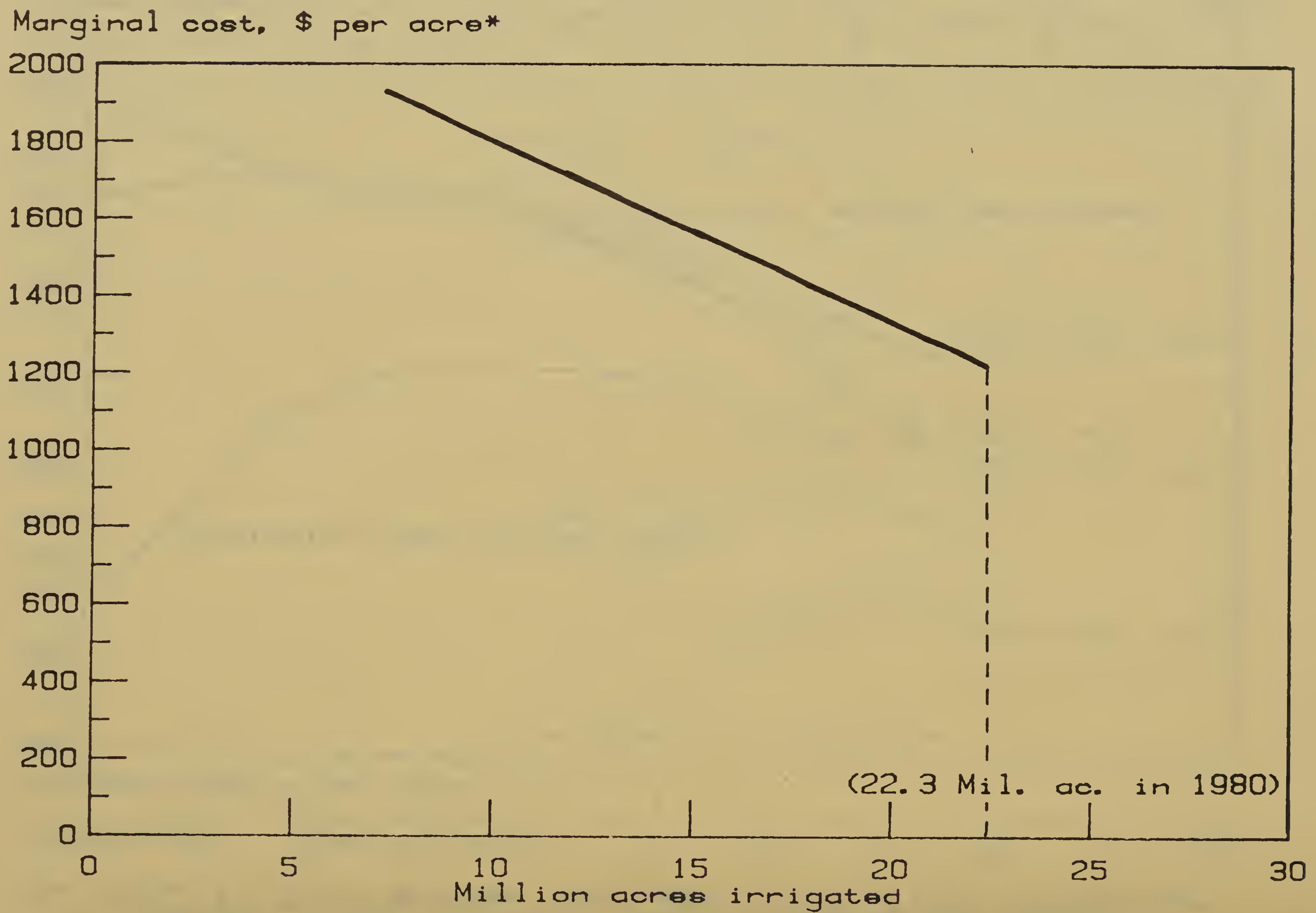
Changing Marginal Cost Of Sprinkler Irrigation In The U.S.: Water Supply And Distribution Systems, 1940-1980



* In constant (1977) dollars. Marginal cost is the added investment required to expand irrigation by 1 acre from the acreage irrigated as of any year shown.

Figure 22

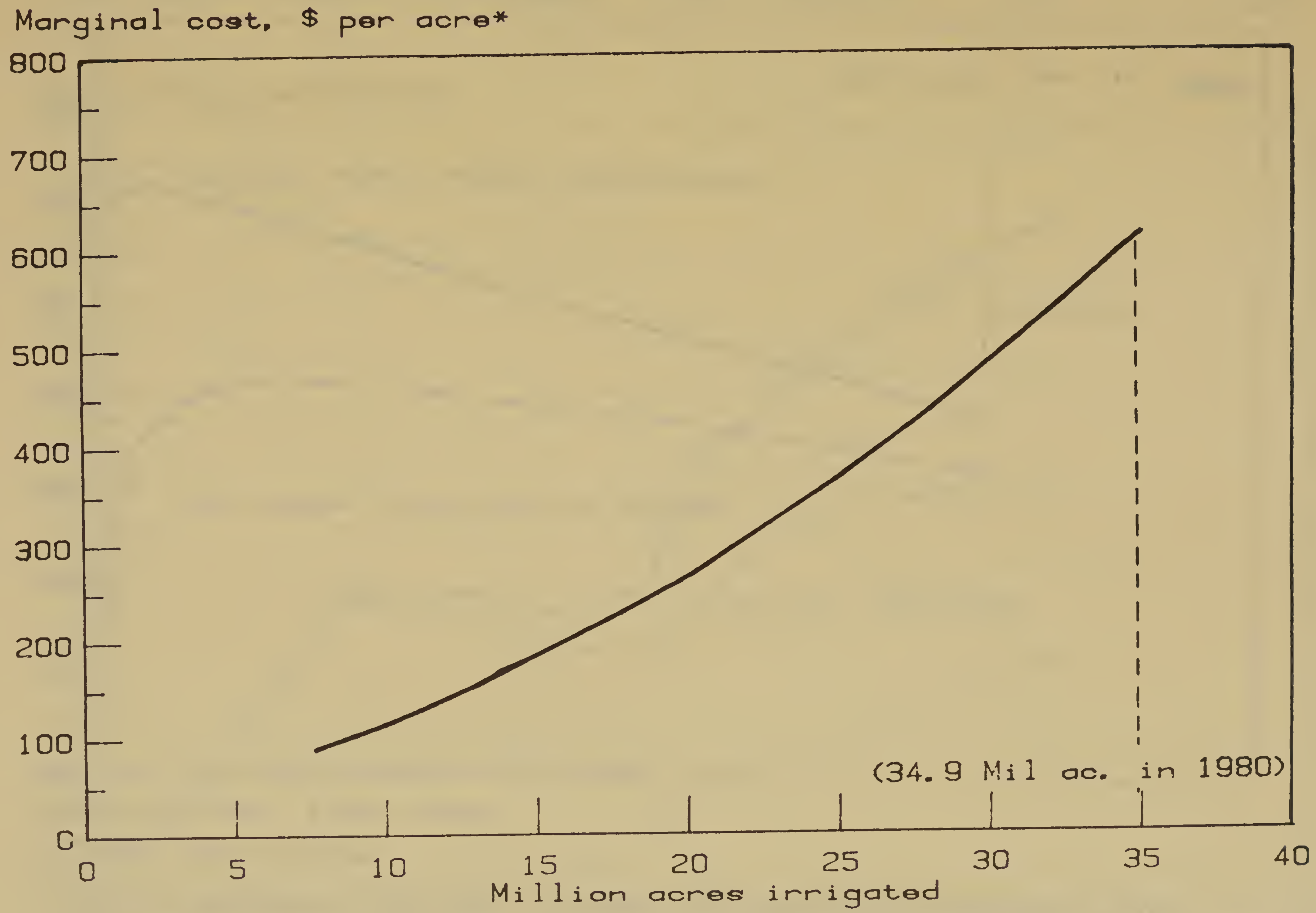
Marginal Cost of Project Irrigation Facilities in The U.S.



* In constant (1977) dollars. Marginal cost is the added investment required to expand irrigation by 1 acre from any indicated total acreage.

Figure 23

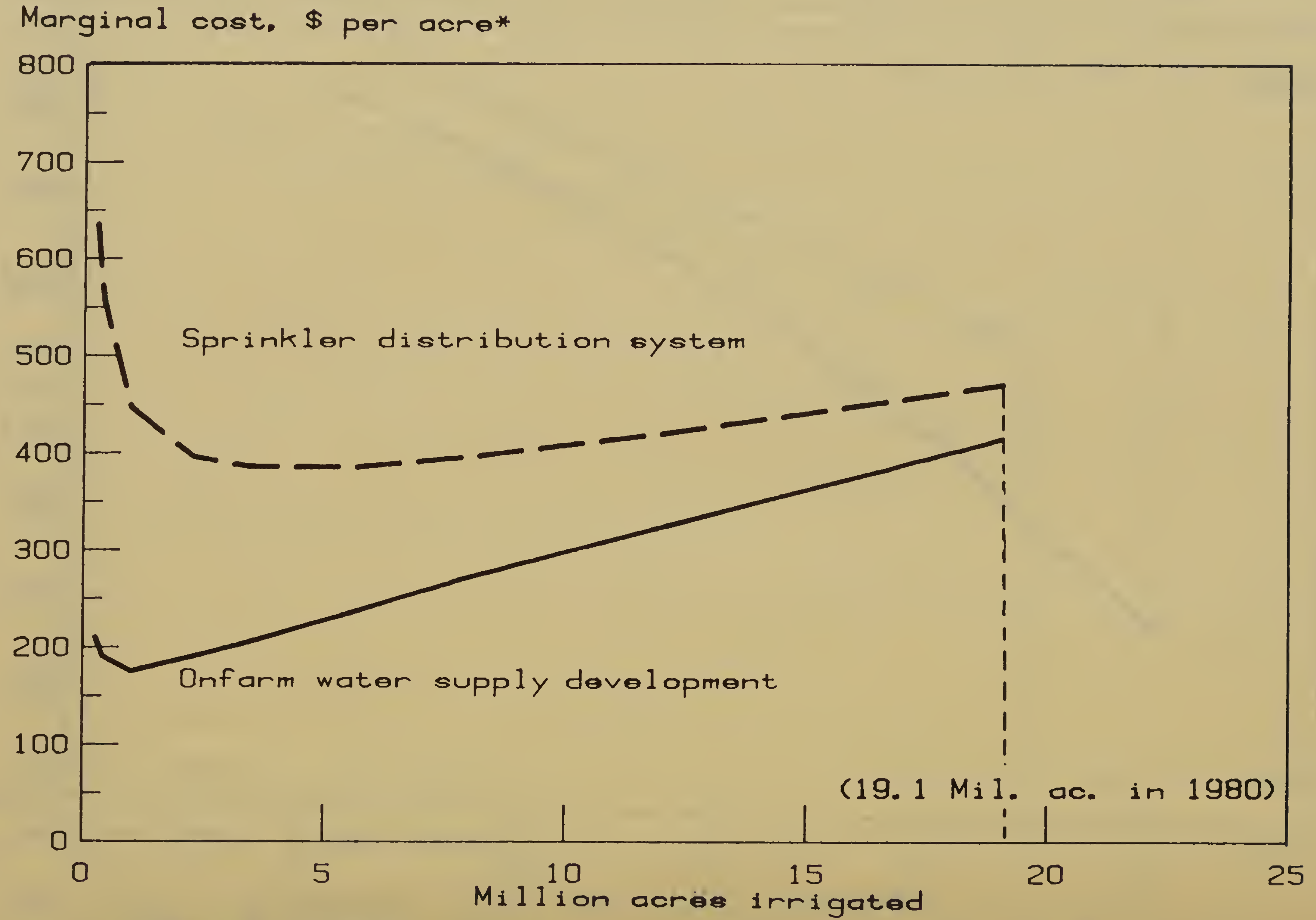
Marginal Cost Of Gravity Irrigation On U.S. Farms



* In constant (1977) dollars. Marginal cost is the added investment required to expand irrigation by 1 acre from any indicated total acreage.

Figure 24

Marginal Cost Of Sprinkler Irrigation On U.S. Farms: Water Supply Development And Distribution



* In constant (1977) dollars. Marginal cost is the added investment required to expand irrigation by 1 acre from any indicated total acreage.

Figure 25

Land Drained In The U.S.: With And Without Project Facilities, 1900-1980

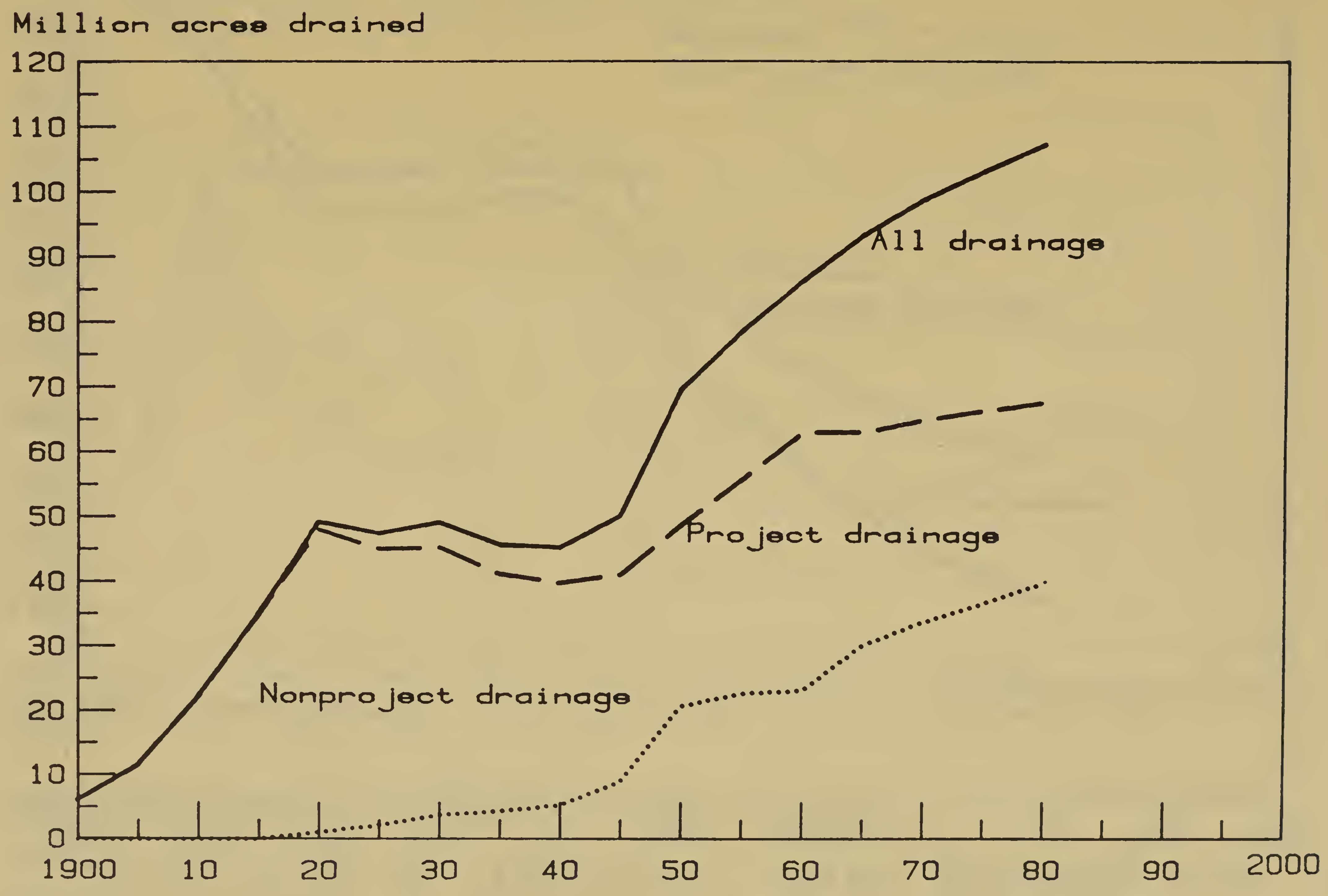


Figure 26

Land Drained In The U.S.: With Surface and Subsurface Systems, 1900-1980

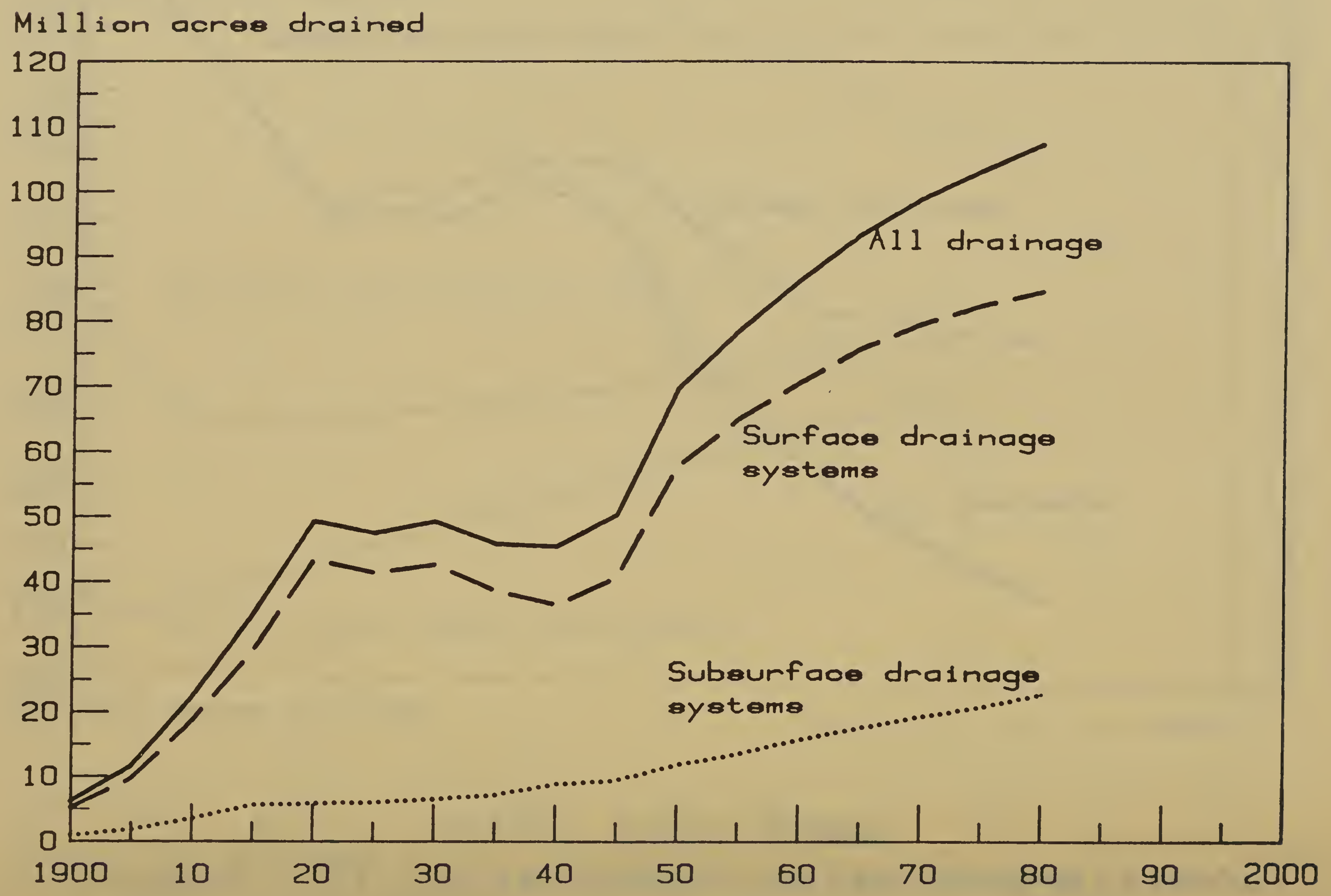
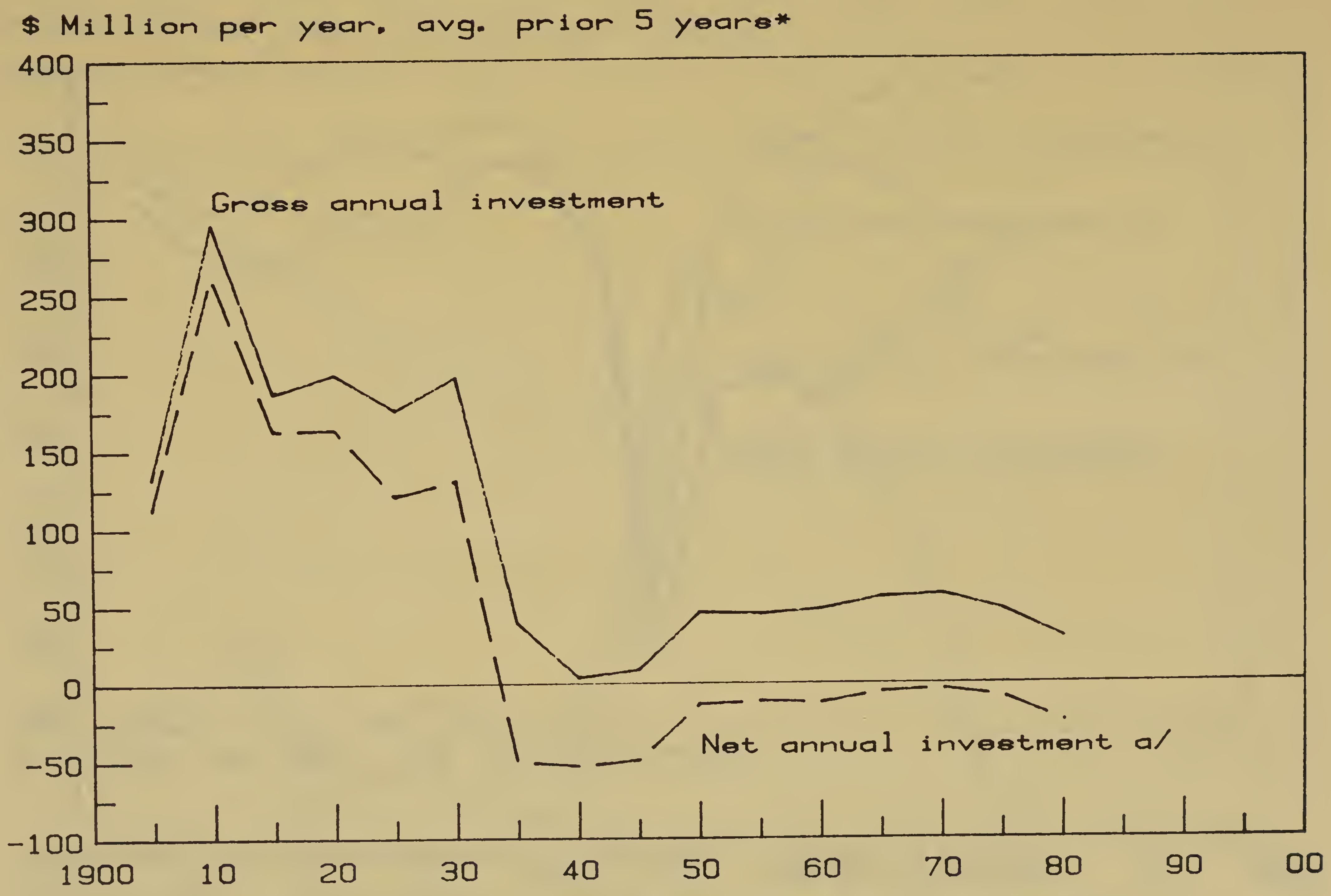


Figure 27

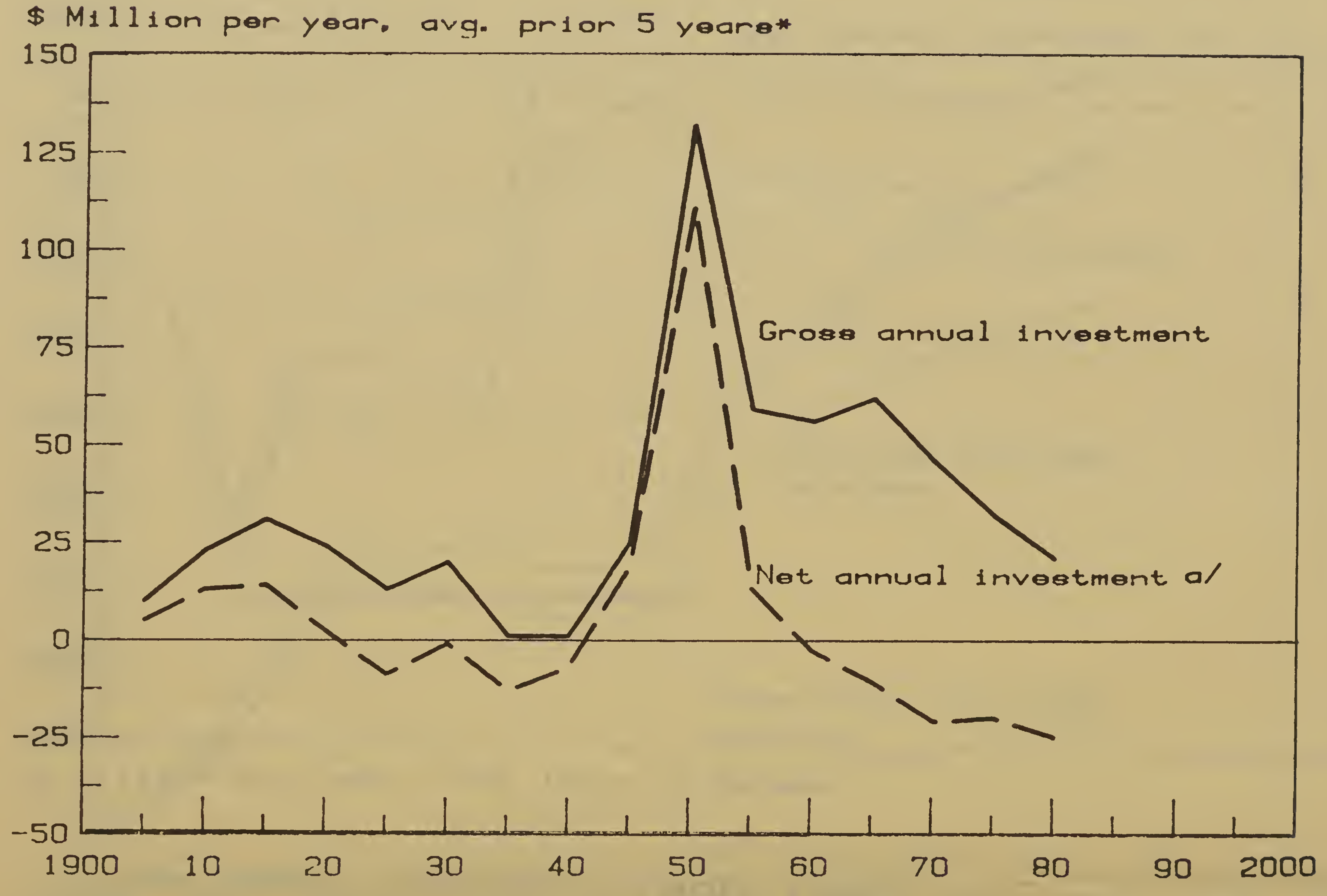
Project Drainage In The U.S.: Annual Investment Trends, 1900-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 28

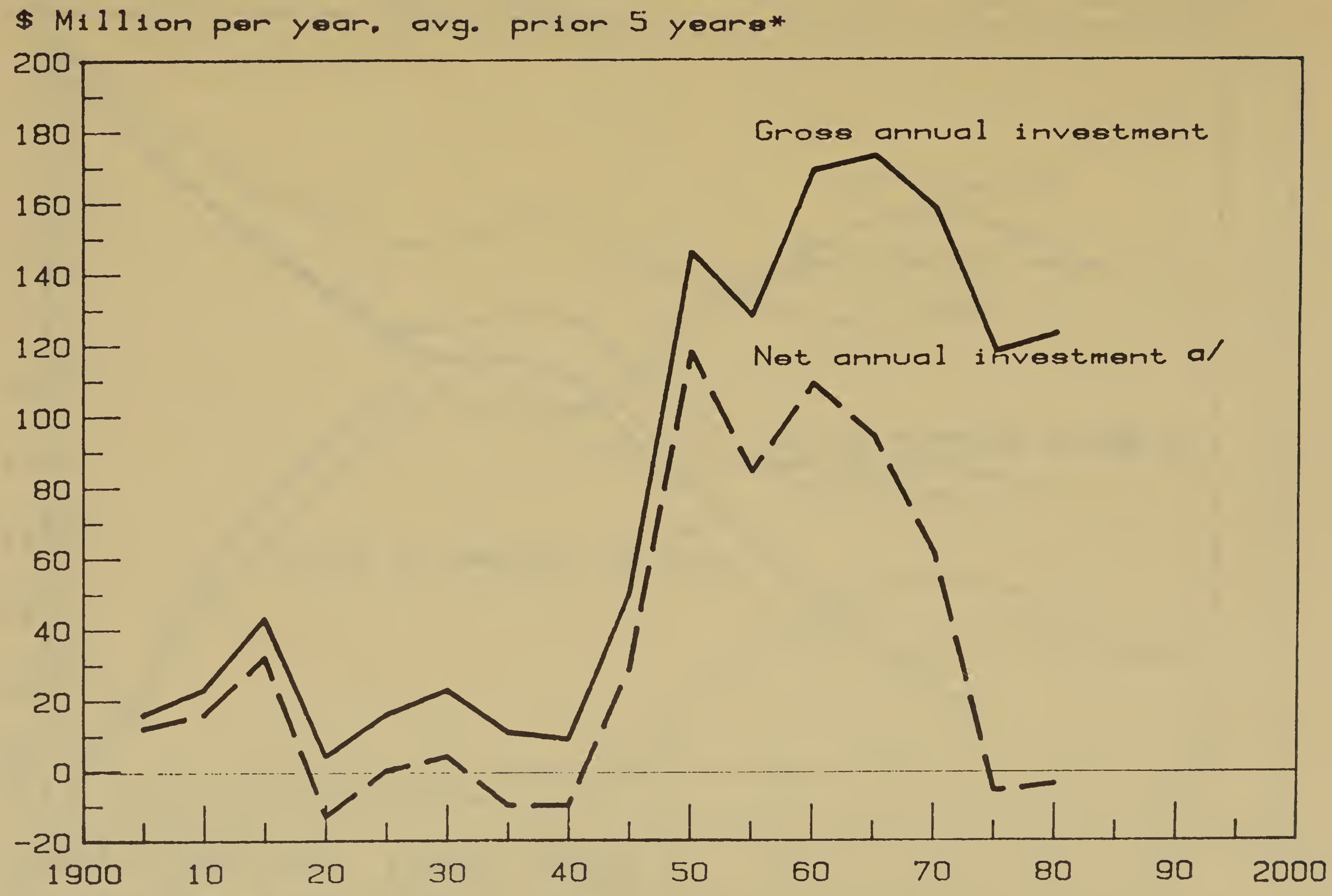
Surface Drainage Systems On U.S. Farms: Annual Investment Trends, 1900-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 29

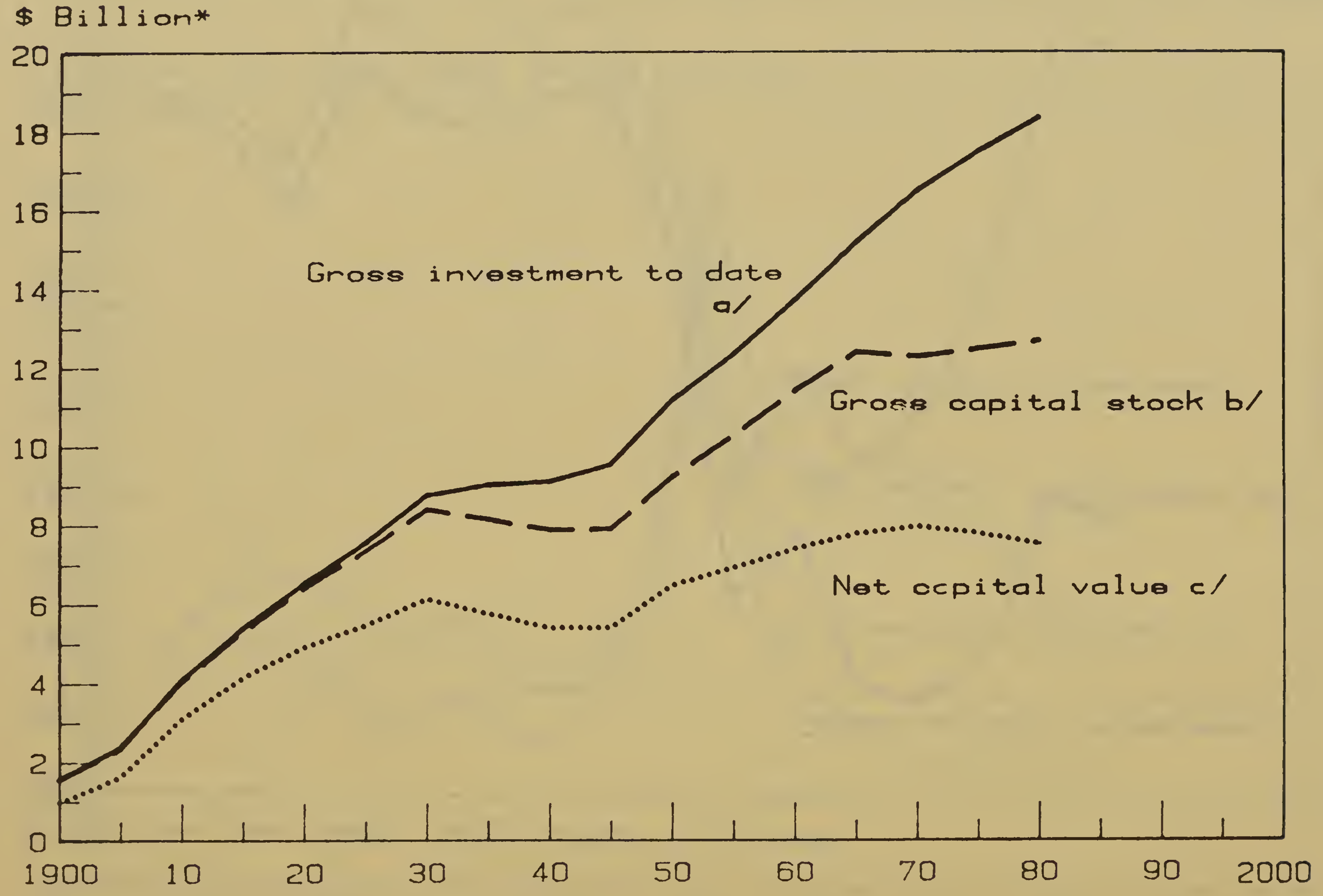
Subsurface Drainage Systems on U.S. Farms: Annual Investment Trends, 1900-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 30

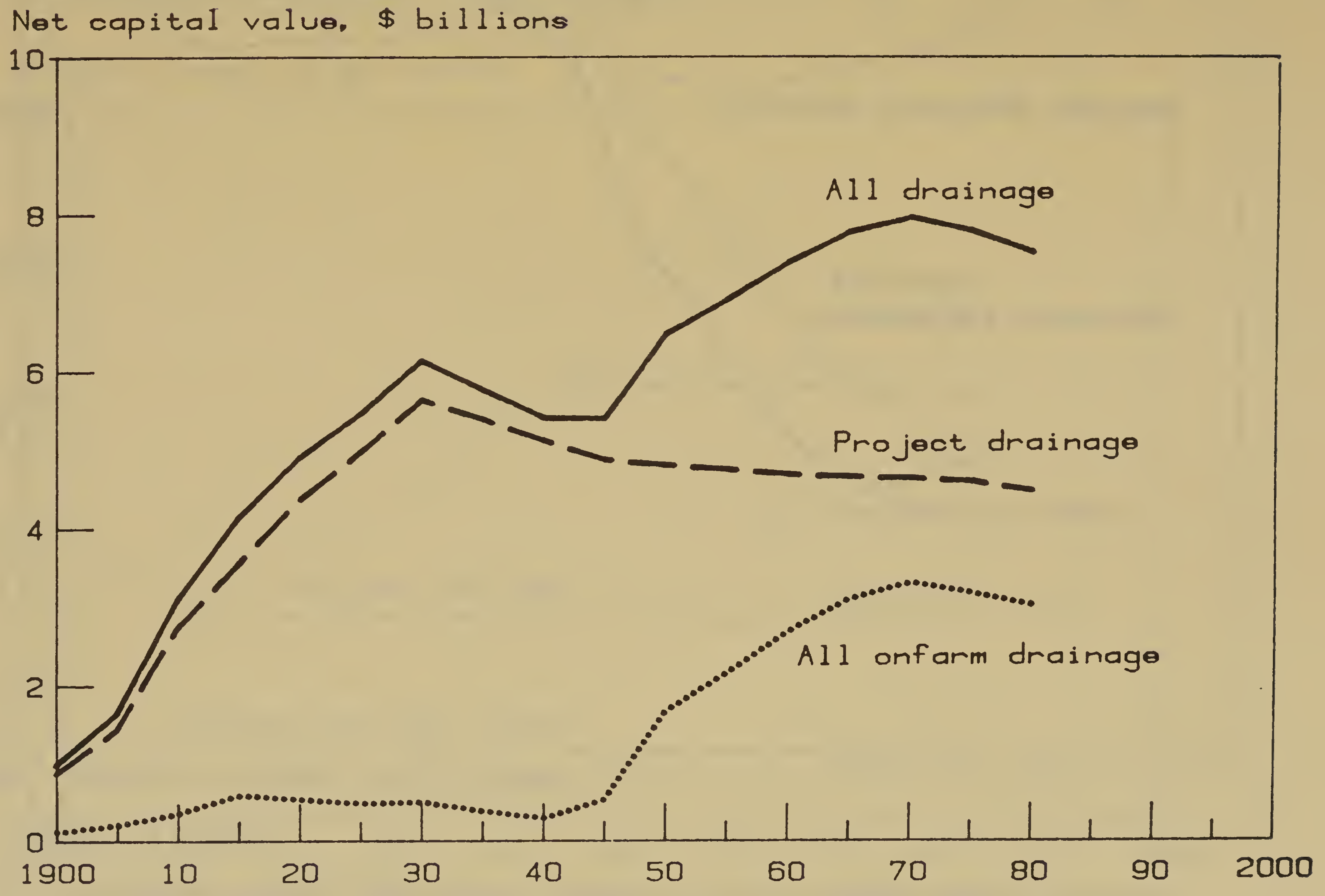
Drainage Capital Formation in U.S. Agriculture, 1900-1980



* In 1977 dollars. a/ Cumulative gross investment in 1977 dollars. b/ Full-cost value of facilities still in use. c/ Net value = depreciated value of facilities still in use, or gross investment to date less depreciation to date.

Figure 31

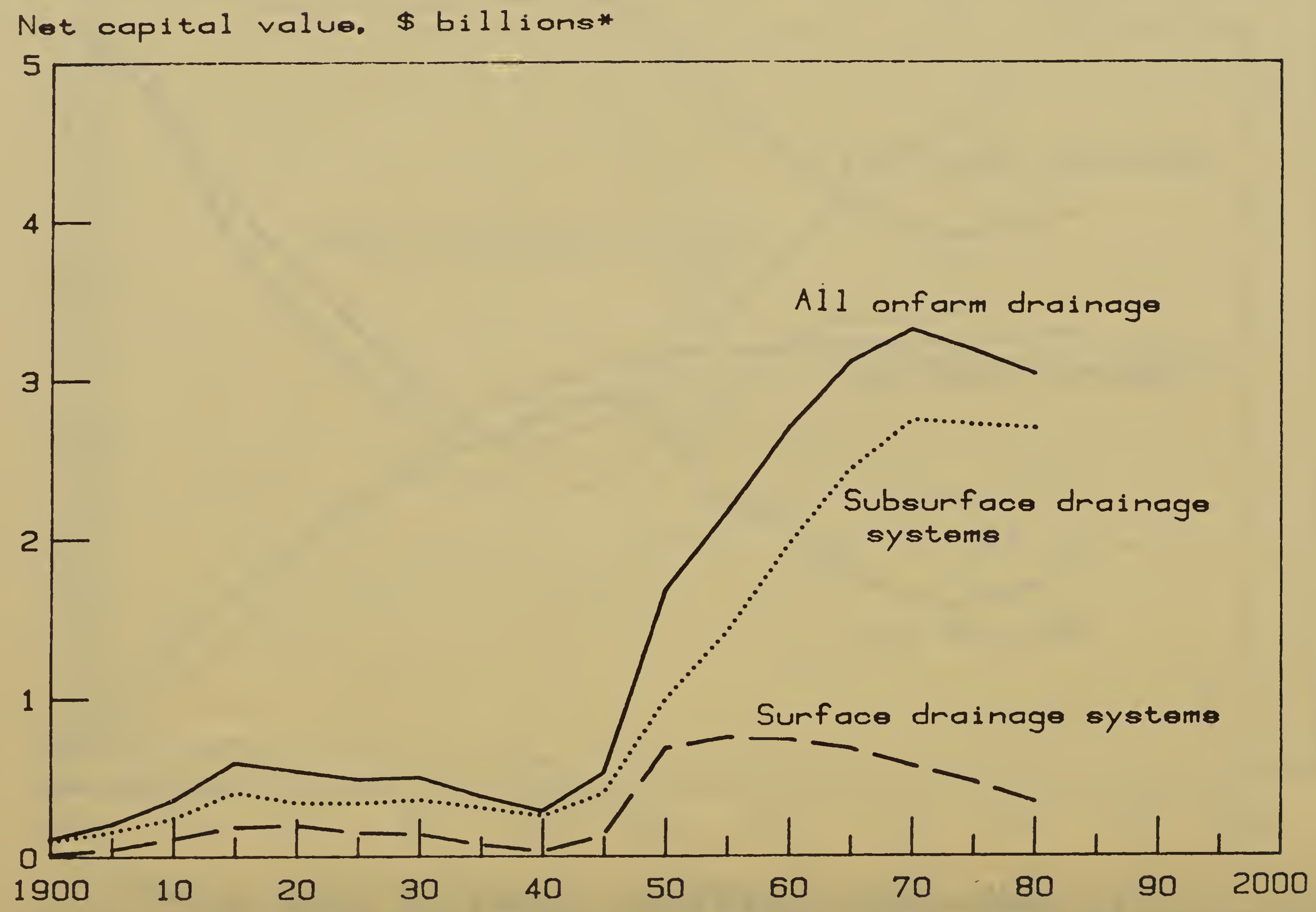
Farmland Drainage Capital In The U.S.: Project And Onfarm Capital Values, 1900-1980



* In 1977 dollars; net value=total investment to date less depreciation to date.

Figure 32

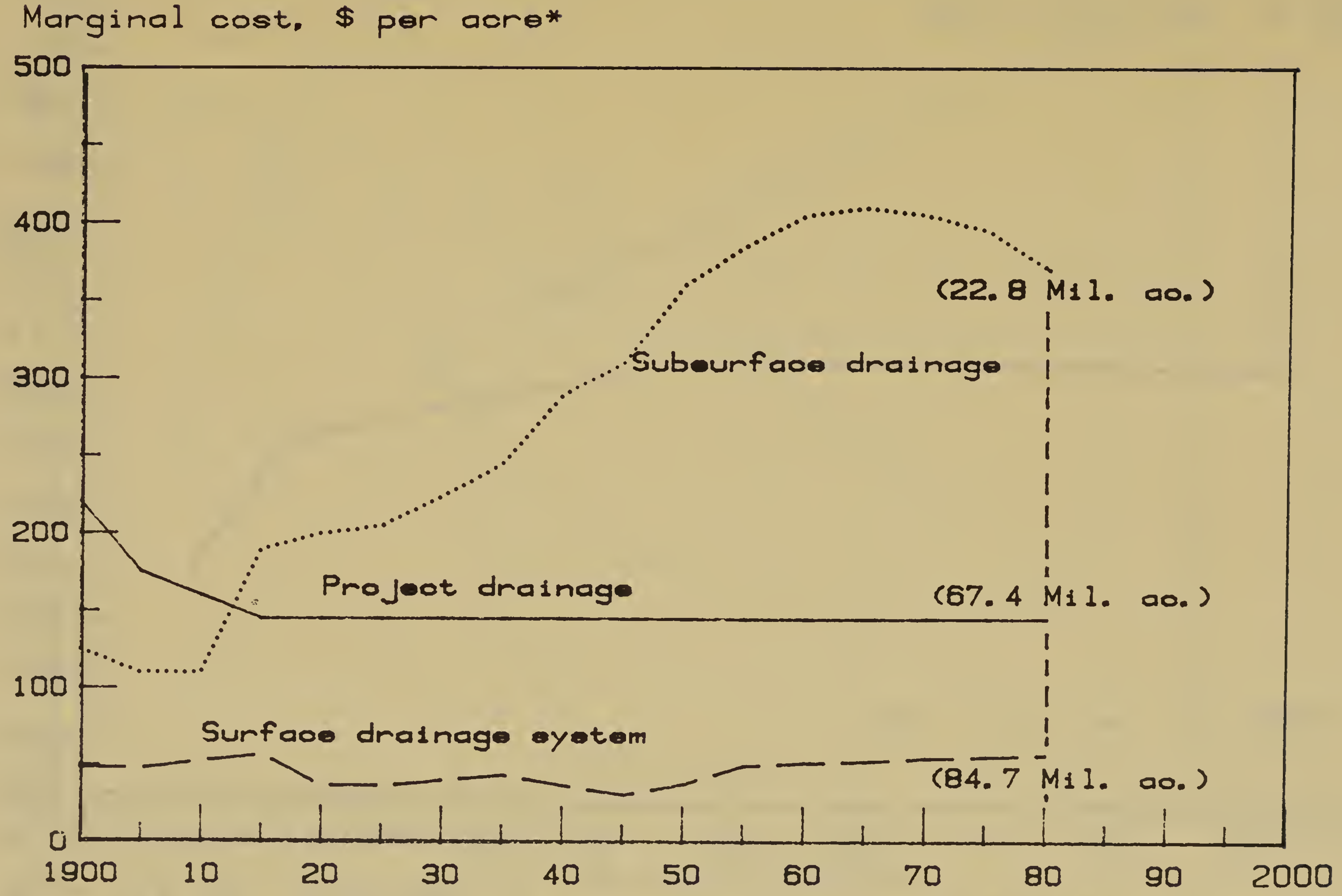
Onfarm Drainage Capital In The U.S.: Surface And Subsurface Drainage Systems, 1900-1980



* In 1977 dollars; net value=total investment to date less depreciation to date.

Figure 33

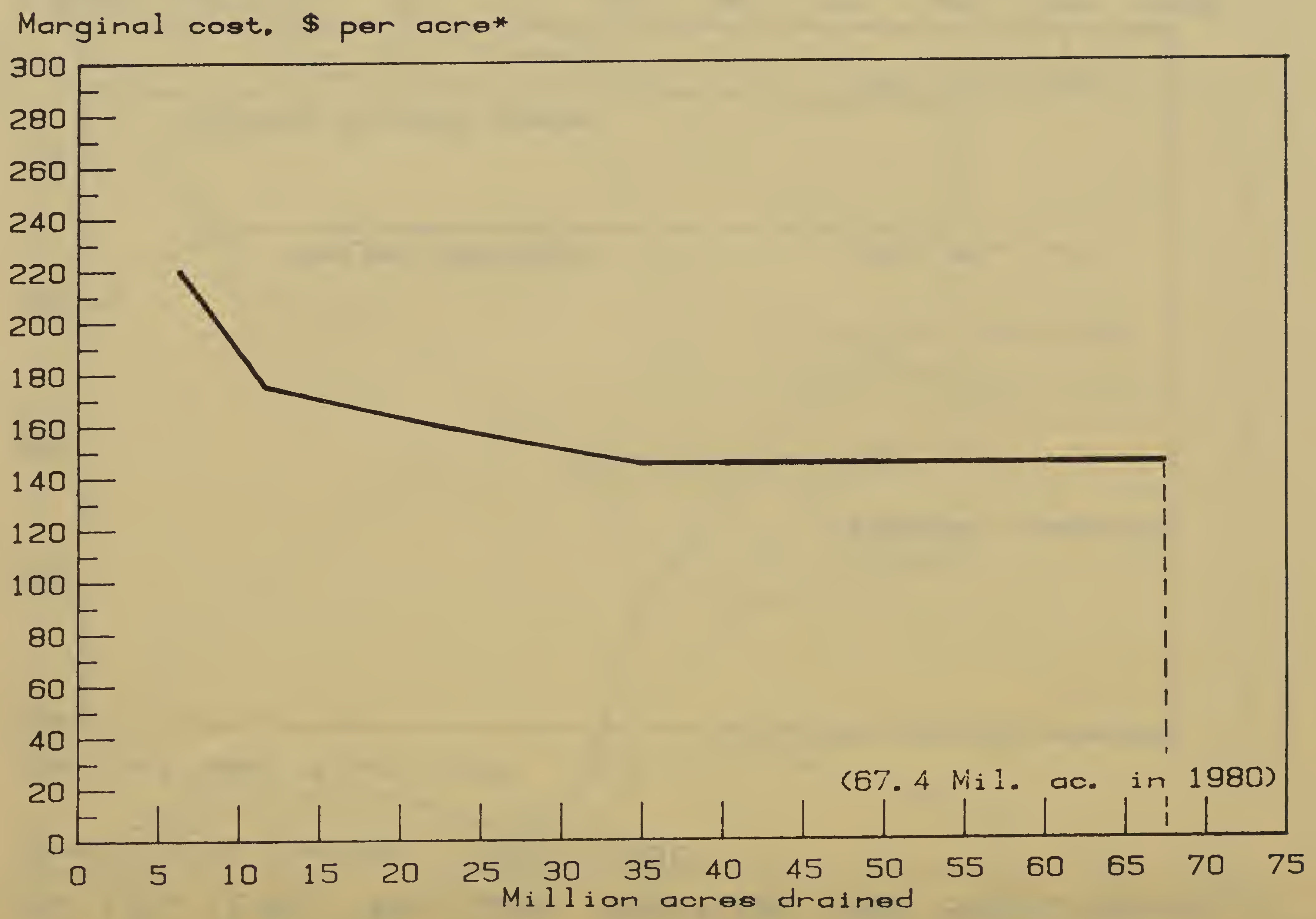
Changing Marginal Cost of Farmland Drainage in the U.S.: Project, Surface and Subsurface Drainage Costs, 1900-1980



* In constant (1977) dollars. Marginal cost is the added investment required to expand drainage by 1 acre from the acreage drained as of any year shown.

Figure 34

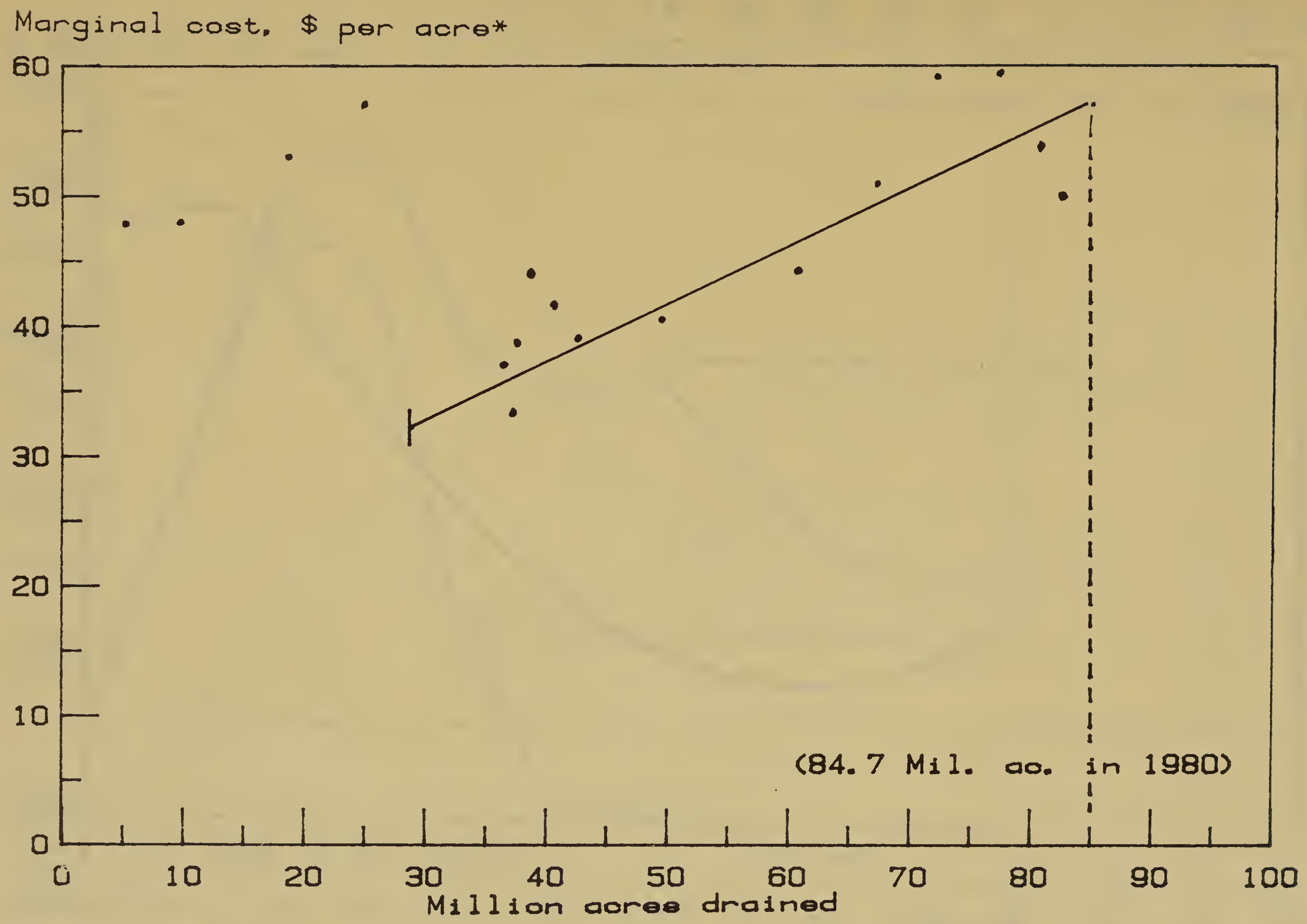
Marginal Cost of Project Drainage Facilities for U.S. Farms



* In constant (1977) dollars. Marginal cost is the added investment required to expand irrigation by 1 acre from any indicated total acreage.

Figure 35

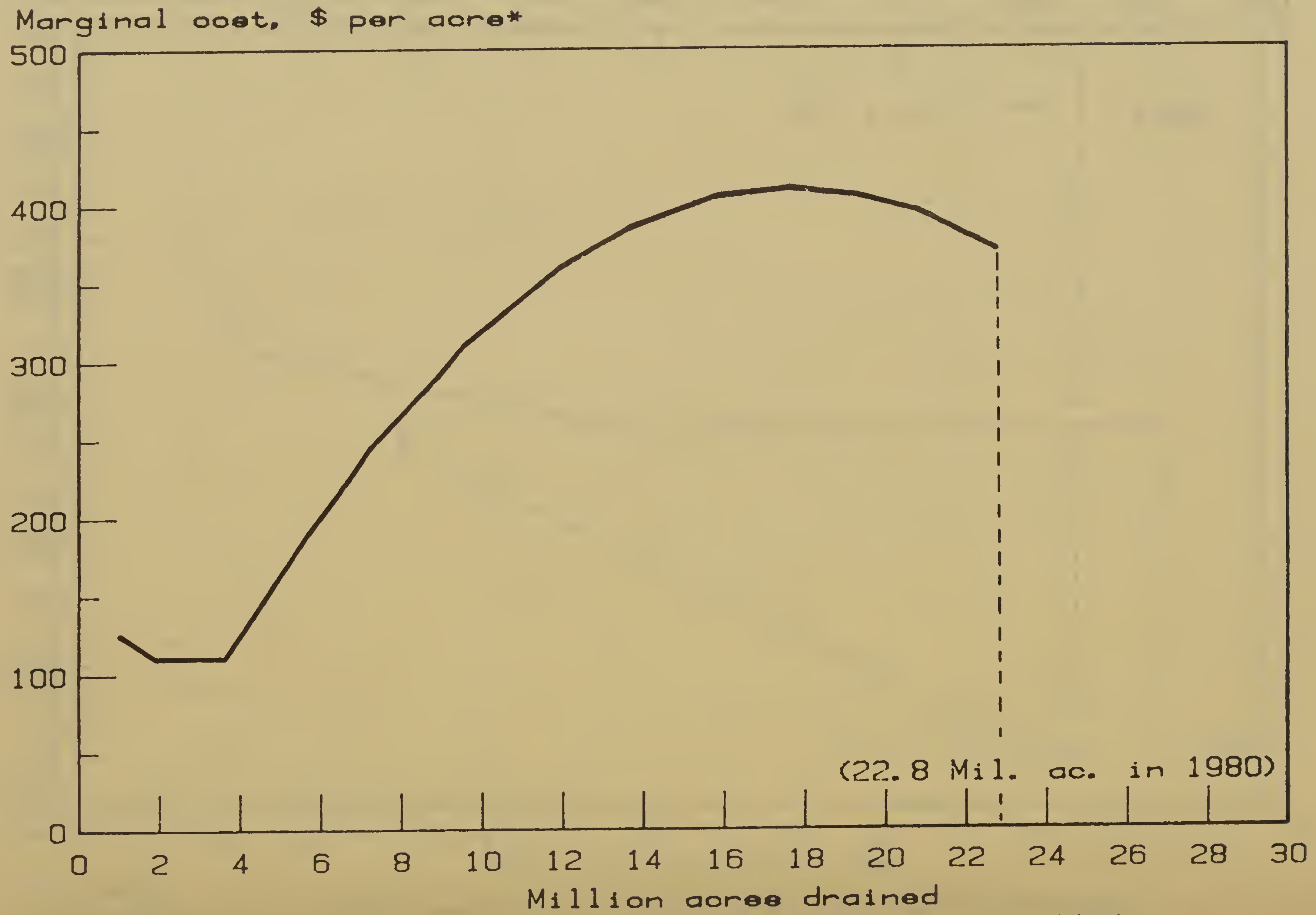
Marginal Cost Of Surface Drainage on U.S. Farms



* In constant (1977) dollars. Marginal cost is the added investment required to expand drainage by 1 acre from any indicated total acreage.

Figure 36

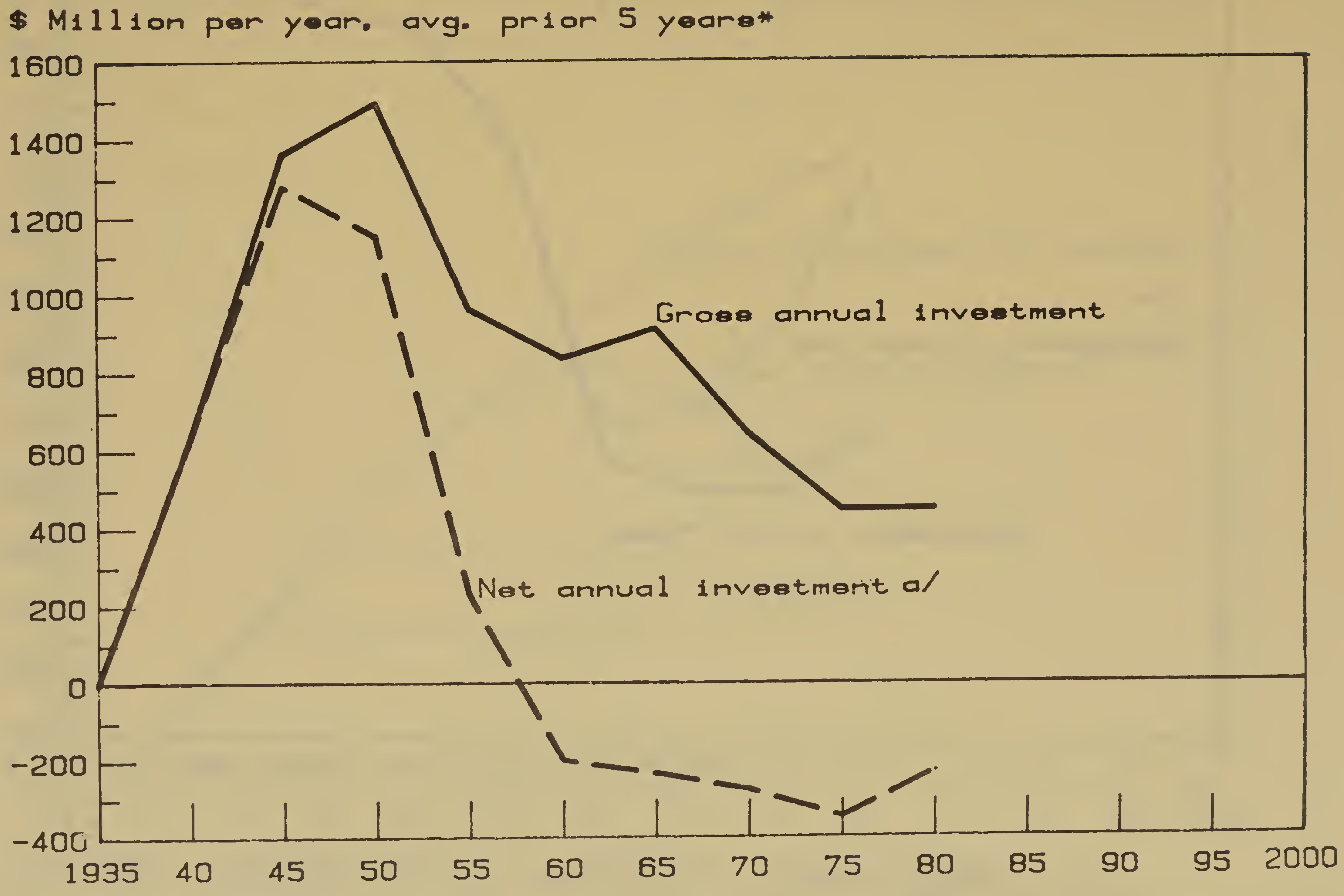
Marginal Cost Of Subsurface Drainage on U.S. Farms



* In constant (1977) dollars. Marginal cost is the added investment required to expand irrigation by 1 acre from any indicated total acreage.

Figure 37

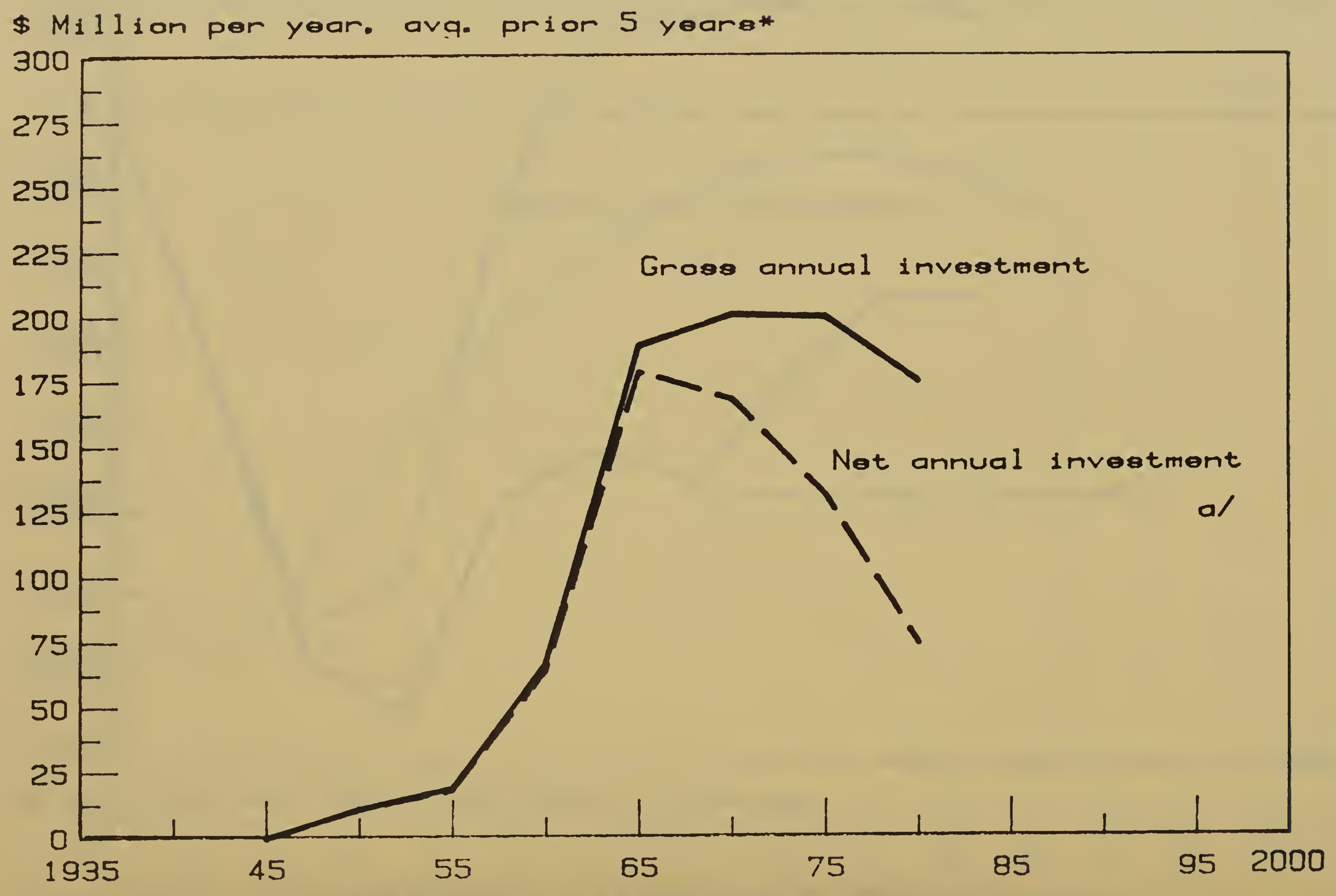
Conservation Measures On U.S. Farms: Annual Investment Trends, 1935-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 38

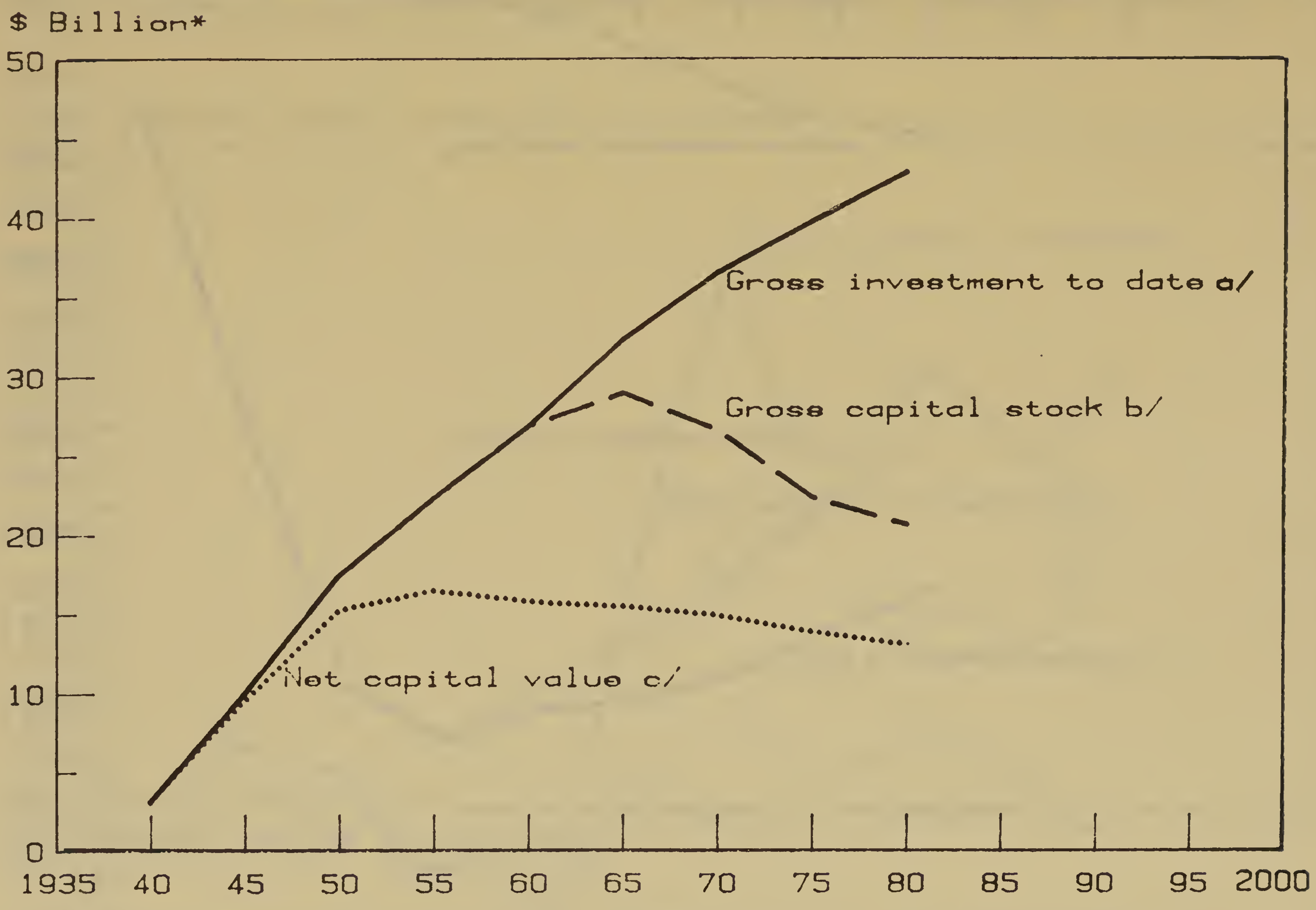
Conservation Projects For U.S. Agriculture: Annual Investment Trends, 1945-1980



* In 1977 dollars. a/ Net annual investment = gross annual investment less annual depreciation allowance.

Figure 39

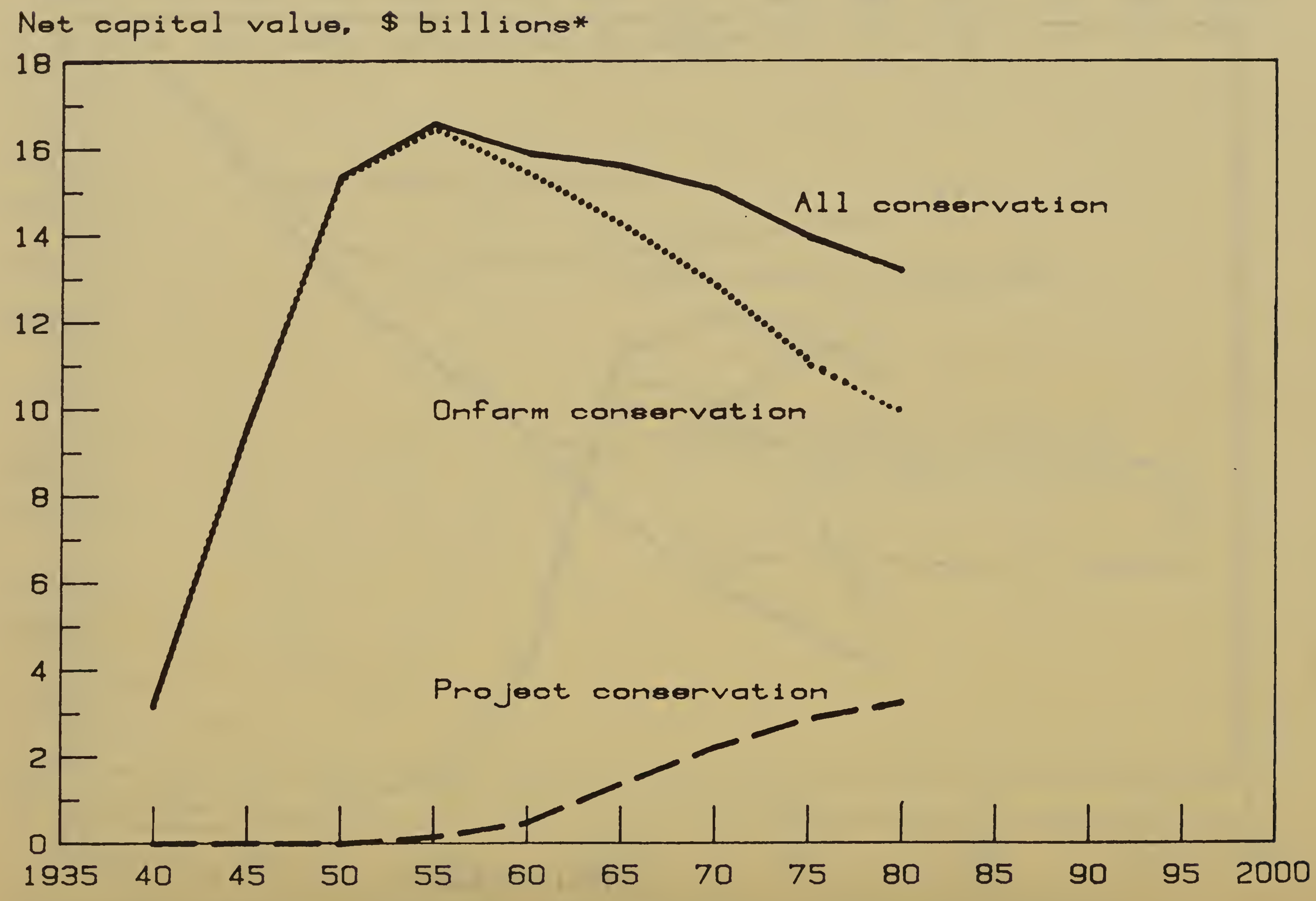
Conservation Capital Formation in U.S. Agriculture, 1935-1980



* In 1977 dollars. a/ Cumulative gross investment in 1977 dollars. b/ Full-cost value of facilities still in use. c/ Net value = depreciated value of facilities still in use, or gross investment to date less depreciation to date.

Figure 40

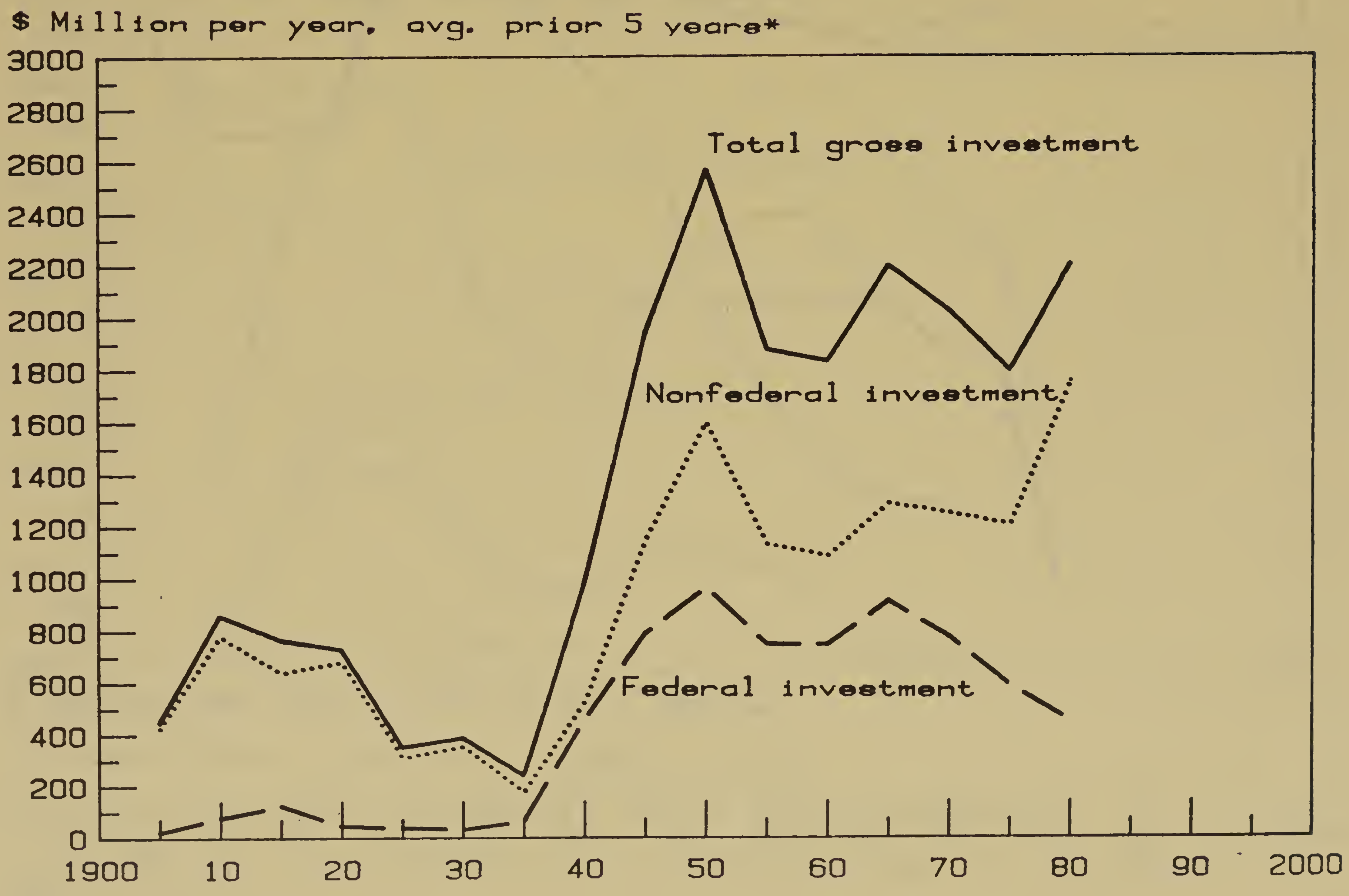
Conservation Capital In U.S. Agriculture: Project And Onfarm Measures, 1935-1980



* In 1977 dollars; net value=total investment to date less depreciation to data.

Figure 41

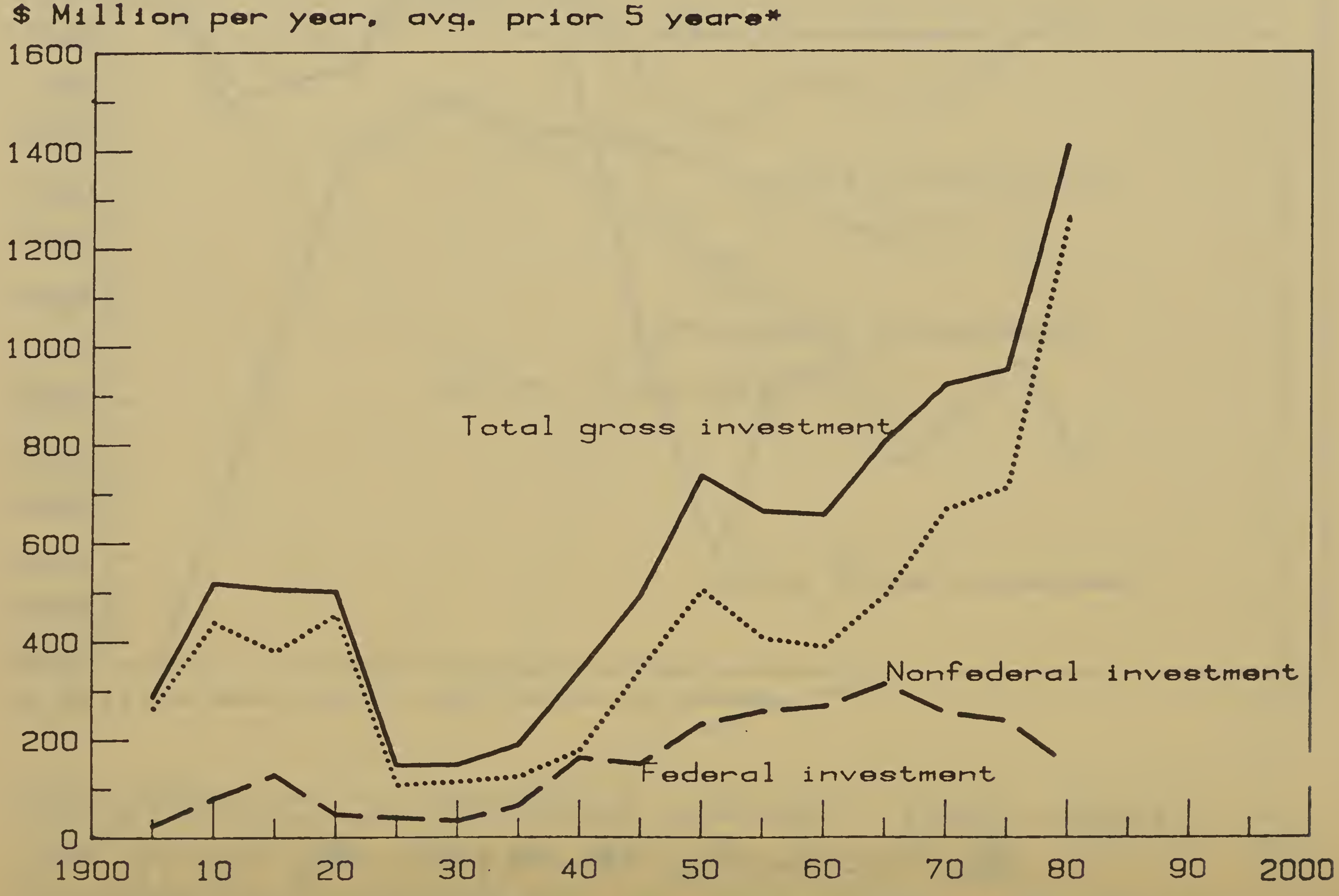
Trends in Natural Resource Investment In The U.S. Agriculture: Federal and Nonfederal Investment Rates, 1900-1980



* In 1977 dollars.

Figure 42

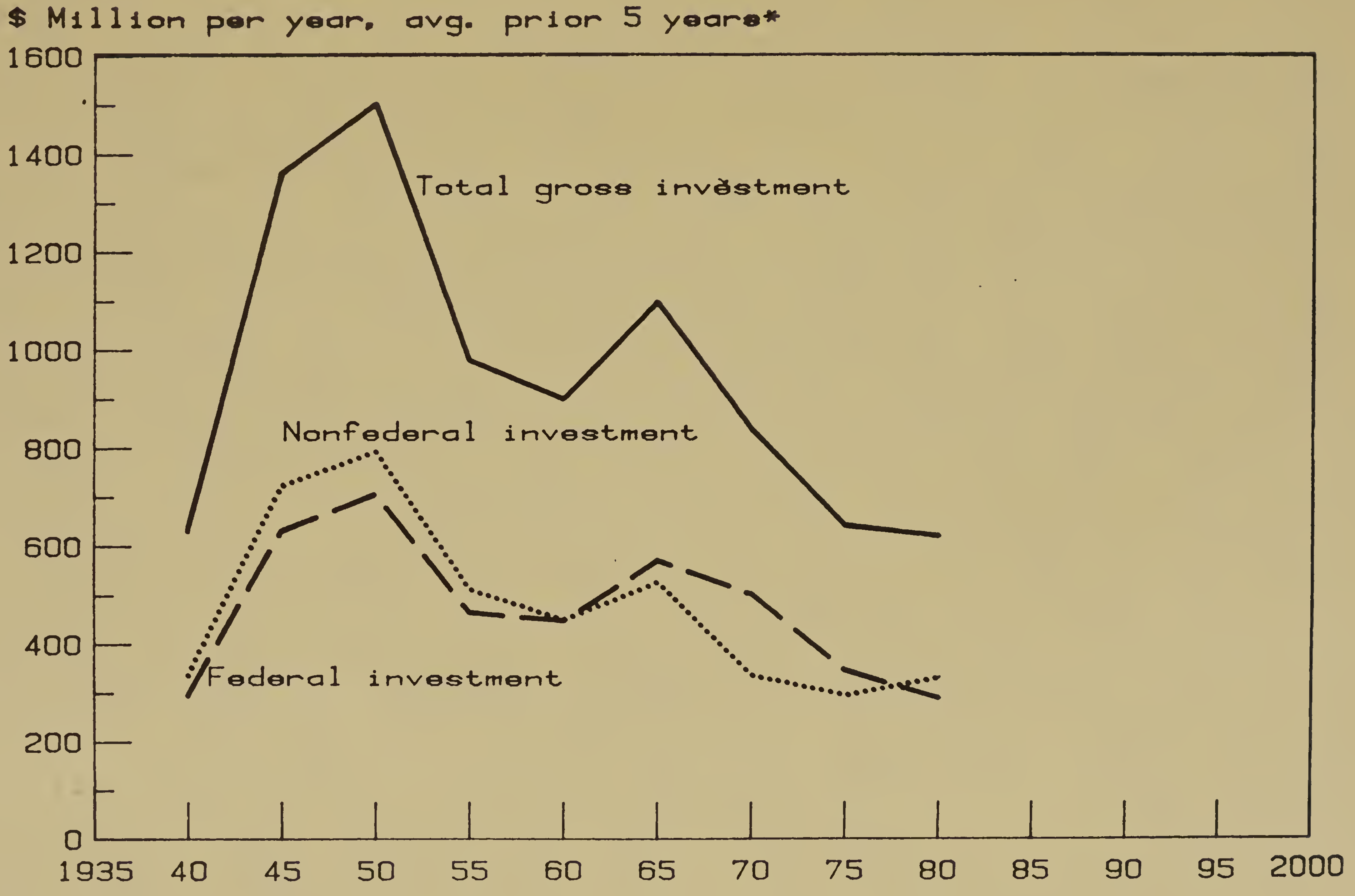
Trends In Irrigation Investment in U.S. Agriculture: Federal and Nonfederal Investment Rates, 1900-1980



* In 1977 dollars.

Figure 43

Trends In Conservation Investment In U.S. Agriculture: Federal and Nonfederal Investment Rates, 1935-1980



* In 1977 dollars.

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